

Preliminary Development and Verification of Multi-Module Integration for the SAFARI Severe Accident Analysis

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***Keywords :** SAFARI, Coupling, SAVANNAH, HIPPO, MAMBA, I-COSTA

1. Introduction

A severe accident in a nuclear power plant is a highly complex multi-physics process involving simultaneous thermal-hydraulic, chemical, and radiological phenomena within the containment. To accurately predict and evaluate these containment phenomena, it is essential to build an integrated analysis system that organically couples detailed physics modules specialized for each phenomenon rather than relying on a single standalone code.

To meet these requirements, research is currently underway to develop the SAFARI (Safety Analysis code For severe Accident Risk Identification) framework, which focuses on the comprehensive analysis of containment severe accident phenomena. The SAFARI framework is designed to efficiently integrate individual detailed modules—such as SAVANNAH[1], MOOFASA[2,3], and I-COSTA[4]—that handle containment thermal-hydraulics, ex-vessel corium behavior, radioactive aerosol behavior within a unified system. However, because each module deals with different physical domains and data structures, establishing and verifying a multi-module coupling scheme to control data is a prerequisite before applying the framework to full-scale containment accident analysis.

As a foundational step toward building the SAFARI framework, this study presents the preliminary development and verification of a multi-module coupling function between key containment modules. A data exchange mechanism and coupling workflow were established, and preliminary verification calculations were performed to confirm the operational functionality and numerical stability of the coupling interface. This paper describes the structure of the implemented coupling scheme and discusses future extension plans based on the verification results.

2. SAFARI Framework and Module Overview

2.1 SAFARI Framework Architecture

The SAFARI framework is a multi-physics modular platform currently under development for integrated accident risk identification and analysis. It focuses specifically on containment phenomena during severe accidents, including containment thermal-hydraulics, ex-vessel corium behavior, and fission product aerosol behavior.

2.2 Overview of Linked Modules

The core physical modules coupled and verified in this preliminary study and their respective roles are as follows:

- **SAVANNAH (Containment Thermal-Hydraulics Module):**
A containment thermal-hydraulics analysis module. Based on a multi-compartment model, it calculates the distribution of steam and non-condensable gases, as well as the pressure and temperature inside the containment.
- **MOOFASA (Ex-vessel Corium Behavior Module):**
A specialized module that simulates ex-vessel corium spreading, Fuel-Coolant Interaction (FCI), and Molten Core-Concrete Interaction (MCCI) in the containment cavity.
- **I-COSTA (Aerosol Behavior Module):**
An aerosol behavior module that analyzes the chemical form changes of fission products, aerosol state transitions, and radioactive material transport/deposition within the containment during an accident.

In this study, a multi-module interface was defined to ensure seamless interactions among these containment-focused modules (e.g., coupling containment thermal-hydraulic boundary conditions from SAVANNAH with aerosol behavior from I-COSTA and ex-vessel thermal loads from MOOFASA).

3. Multi-Module Coupling Scheme

Multi-module coupling within the SAFARI framework is managed by a Master Module to minimize

direct dependencies between individual modules and ensure high extensibility. Each module (SAVANNAH, MOOFASA, I-COSTA) is developed as a library, exchanging input and output state variables in standardized data structures via Application Programming Interfaces (APIs) provided by the framework.

- Thermal-Hydraulics ↔ Aerosol Coupling (SAVANNAH ↔ I-COSTA):

The compartment thermal-hydraulic states and heat structure wall temperatures calculated by SAVANNAH are passed to I-COSTA as boundary conditions. Based on these inputs, I-COSTA calculates aerosol deposition, concentration. The resulting reaction heat is then fed back as a source term in SAVANNAH's mass and energy conservation equations.

- Corium ↔ Thermal-Hydraulics Coupling (MOOFASA ↔ SAVANNAH):

The thermal-hydraulic conditions of the containment cavity calculated by SAVANNAH are transferred to MOOFASA as boundary conditions. MOOFASA calculates corium fragmentation and spreading due to FCI, as well as subsequent MCCI behavior. The generated heat and non-condensable gases from these processes are fed back to SAVANNAH as source terms in its mass and energy conservation equations.

4. Preliminary Verification

To verify the data transfer accuracy and inter-module interactions of the developed coupling scheme, preliminary coupled analyses were conducted using standard verification problems from MOOFASA and I-COSTA. The performance and physical behavior predictions of the coupling interface were evaluated by comparing standalone calculations with coupled calculations.

4.1 SAVANNAH - MOOFASA Coupling Verification

Figures 1 through 3 compare the results of the standalone MOOFASA calculation with the coupled SAVANNAH-MOOFASA calculation for the same test case. The comparison revealed the following thermal-hydraulic and corium behavior characteristics:

- Corium Average Temperature Prediction: The overall trend of corium average temperature change was appropriately predicted during the coupled calculation.

- Heat Transfer and Thermal-Hydraulic State Changes: The heat flux transferred from the corium to the containment atmosphere was predicted to be higher in the coupled analysis compared to the standalone calculation. This difference in heat transfer led to variations in key containment thermal-hydraulic state variables, such as containment pressure.

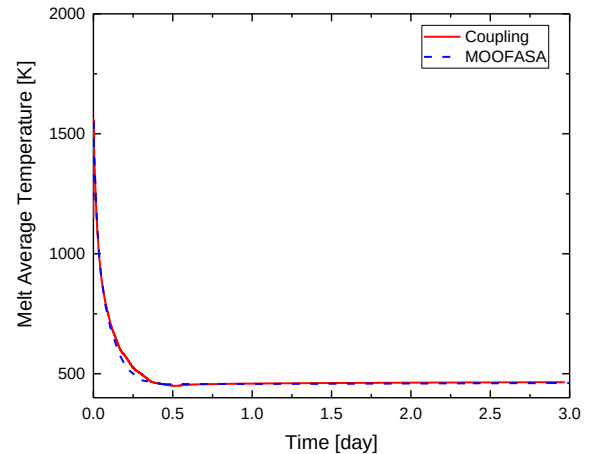


Fig. 1. Coupling verification: corium average temperature

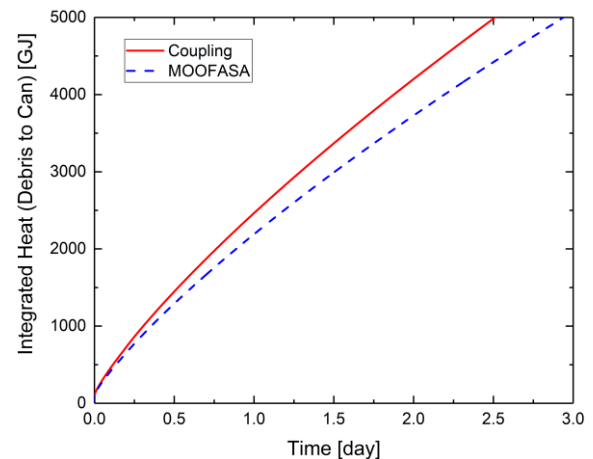


Fig. 2. Coupling verification: integrated transferred heat

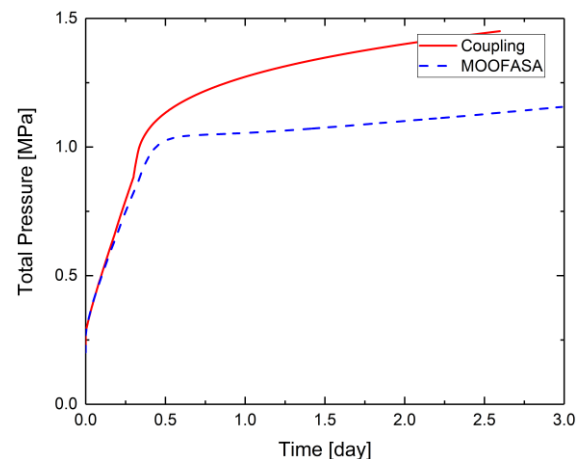


Fig. 3. Coupling verification: containment pressure

4.2 SAVANNAH - I-COSTA Coupling Verification

Figures 4 and 5 compare the standalone I-COSTA calculation with the coupled SAVANNAH-I-COSTA calculation.

- **Aerosol Concentration Behavior:** The overall time-dependent trend of aerosol concentration in the atmosphere was predicted similarly in both standalone and coupled calculations.
- **Deposition Behavior Influence:** As time progressed, aerosols deposited onto containment walls and floors. The coupled calculation predicted a slightly higher aerosol deposition rate than the standalone I-COSTA calculation. Consequently, both individual aerosol species concentrations and the total aerosol concentration were predicted to be slightly lower in the coupled simulation due to the real-time thermal-hydraulic feedback.

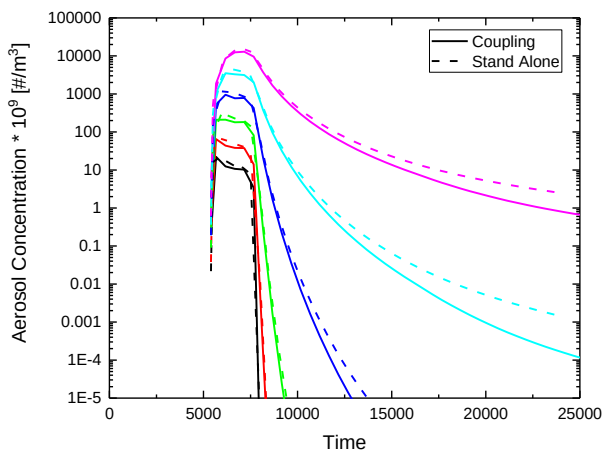


Fig. 4. Coupling verification: aerosol concentration

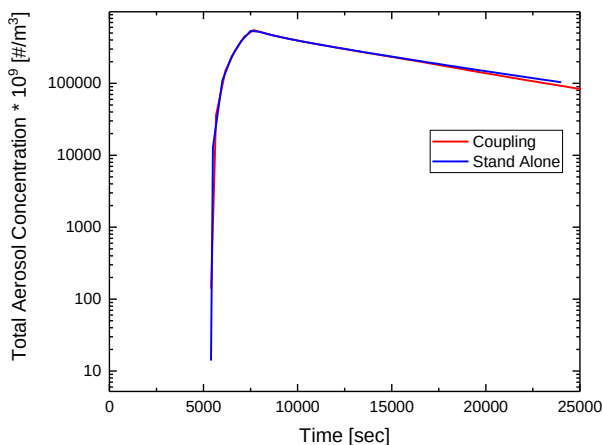


Fig. 5. Coupling verification: total aerosol concentration

5. Conclusions and Future Work

In this study, as part of the development of the SAFARI, a multi-module coupling scheme was

established among key detailed modules—SAVANNAH, MOOFASA, and I-COSTA—and its performance was verified through preliminary test cases.

Coupling Functionality: Preliminary coupled simulations using standard verification problems demonstrated that corium temperature trends and overall aerosol concentration behavior were well captured, showing consistency with standalone calculations while accounting for feedback effects.

Observed Differences & Insights: In the coupled analysis, heat transfer from corium to the containment atmosphere was predicted lower, leading to differences in containment thermal-hydraulic responses. Additionally, a slightly higher aerosol deposition rate was observed, resulting in lower airborne aerosol concentrations in the containment atmosphere.

Future work will focus on investigating the physical and numerical causes of these observed differences in heat transfer and aerosol deposition to refine the inter-module feedback mechanisms

ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission(NSSC) of the Republic of Korea. (No. RS-2021-KN051610)

REFERENCES

- [1] K. H. Han, J. Lee, and Y.-J. Choo, Development of the SAFARI Code for Comprehensive Severe Accident Analysis in Nuclear Reactors: Containment Thermal-Hydraulics Analysis Module, Proceedings of the 12th European Review Meeting on Severe Accident Research (ERMSAR2026), May 18-22, 2026, Madrid, Spain.
- [2] M. Kwon, E. S. Kim, H. S. Park, and S. Whang, Development of the SAFARI Code for Comprehensive Severe Accident Analysis in Nuclear Reactors: Corium-Coolant Interaction Analysis Module, Proceedings of the 12th European Review Meeting on Severe Accident Research (ERMSAR2026), May 18-22, 2026, Madrid, Spain.
- [3] J. S. Choi, T. H. Kim, J.-W. Kim, E. S. Kim, and H. S. Park, Development of the SAFARI Code for Comprehensive Severe Accident Analysis in Nuclear Reactors: Molten Core-Concrete Interaction Analysis Module, Proceedings of the 12th European Review Meeting on Severe Accident Research (ERMSAR2026), May 18-22, 2026, Madrid, Spain.
- [4] Y. Lee et al., "Coupling scheme of multicomponent sectional equations and Mason equations via transition rate matrix of hygroscopic growth applied to international standard problem No. 44", Ann. Nucl. Energy, 127, pp437-449, 2019.