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Preliminary Evaluation on Radioactive Material Filtration System Effectiveness under Development

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1. Introduction

After the Fukushima accident, lots of safety systems have been developed, and the safety of domestic nuclear power plants(NPPs) has also improved. To further improve the safety of NPPs, it is necessary to development of radioactive material filtration system which operates in containment to minimize damage caused by release of radioactive material to the environment during the severe accident.

The goal of this project is the development of a passive radioactive material filtration system which can be applied the operating nuclear power plants. Before developing the passive radioactive material filtration system development, it is needed to confirm the effect of fission product removal efficiency when applying the radioactive material filtration system inside containment.

KAERI is developing the fission product removal model by the filtration system using SIRIUS code. In this study, preliminary analysis was performed to evaluate the effectiveness of the radioactive material filtration system based on SLOCA (Small break Loss Of Coolant Accident) scenario.

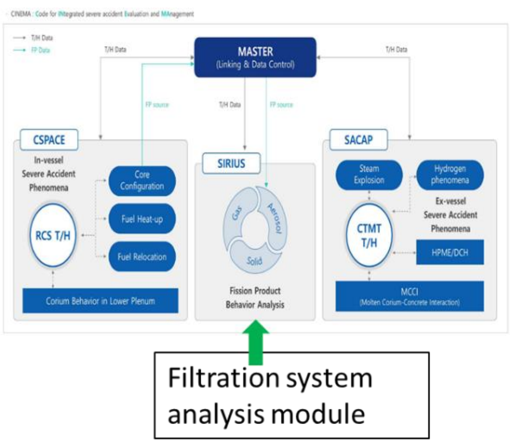

Fig. 1 Concept of filtration system analysis module

2. Analysis Results

2.1 Fission Product Removal Model

The CINEMA code is a computer program that can evaluate the whole process of a severe accident. It can simulate and analyze the processes such as normal operation, core heat-up, melting, relocation, and corium release to containment due to in-vessel damage, corium-concrete reaction, containment pressurization, and fission product behavior and containment failure. The CINEMA code consists of the in-core phenomenon analysis module (CSPACE), the ex-core phenomenon analysis module (SACAP), and the module to analyze the fission product behavior (SIRIUS).

SIRIUS analyzes the behavior of fission products generated in the core and containment by a severe accident. It simulates generation and transport of aerosol fission products inside RCS, transfer to each compartment in the RCS, condensation, evaporation, adsorption, collision, gravitational settling, diffusion, and wall sticking by temperature. It also calculates the distribution of fission products that are released from the RCS or core into the containment and fission products that are generated by a severe accident outside the reactor and are present in each node of the compartment. The radionuclides are classified in 8 groups as described in Table.1.

Table 1 Inventory groups of solid fission products

Group	Represe ntative	Species member
1. Noble gases	Xe	Xe, Kr
2. Alkali metal iodides	I	I
3. Alkali metal hydroxides	Cs	Cs
4. Chalcogens	Te	Te, Sb, Se
5. Alkaline earths	Ba	Ba, Sr
6. Platinoids	Ru	Ru, Mo
7. Rare earths	La	La, Zr(fission)
8. Structural materials	Zr	Zr, Fe, Cr, Ni, Mn,

The aerosol elimination model simulates the decrease of aerosol mass by various physical phenomena. There are five aerosol elimination models in SIRIUS which are the sedimentation(λ_{sed}) which refers to the aerosols dropping onto the RCS bottom by gravitation, the inertial impaction(λ_{imp}) which refers to the aerosols colliding and depositing to the wall in the curved pipe section, the thermophoresis(λ_{th}) which refers to the aerosols moving toward the surrounding cold wall and depositing on it, the diffusiophoresis (λ_{diff}) which refers to the aerosols colliding and depositing to the wall due to the dispersion by aerosol concentration difference, and the spray effect (λ_{sp}). The analysis uses the concept of total elimination coefficient, λt, with the correlation shown in following equation. The unit of total elimination coefficient (λt) is “1/s.”. The calculation multiplies it by the aerosol mass to simulate the decrease rate of aerosol mass [1].

$$\lambda_t = \lambda_{sed} + \lambda_{imp} + \lambda_{diff} + \lambda_{th} + \lambda_{sp} \quad (1)$$

The model for obtaining filtration system elimination coefficient (λ_{fp}) was developed in SIRIUS in Fig.1 and the Eq.(1) was modified as following equation.

$$\lambda_t = \lambda_{sed} + \lambda_{imp} + \lambda_{diff} + \lambda_{th} + \lambda_{sp} + \lambda_{fp} \quad (2)$$

The aerosol elimination coefficient by filtration system is obtained by following equation.

$$\lambda_{fp} = aerosol\ mass\ flow\ rate\ entering\ the\ filtration\ system \div aerosol\ mass\ in\ node \times aerosol\ capture\ efficiency\ of\ filtration\ system \times no.filtration\ system$$

The mass flow rate entering the filtration system and aerosol capture efficiency of the filtration system will be changed by the conditions of the containment. The models which calculates mass flow rate entering the filtration system and aerosol capture efficiency will be developed based on the experiments.

In preliminary analysis, it is assumed that the mass flow rate entering the filtration system increases with the hydrogen concentration, and the changes of aerosol mass in the containment according to aerosol capture efficiency were observed to evaluate the effectiveness of the radioactive material filtration system.

2.2 Analysis results

A newly developed code CINEMA Beta 2.0 is exercised for preliminary evaluation on radioactive material filtration system effectiveness on OPR1000 nuclear power plant. SLOCA initiated severe accident was selected for the accident scenario. SACAP containment model for OPR1000 is illustrated in Fig.2 [2]. The containment has 6 subcompartment volumes and 17 flow paths. The elevations of each control volume and the flow path is specified in Fig.2.

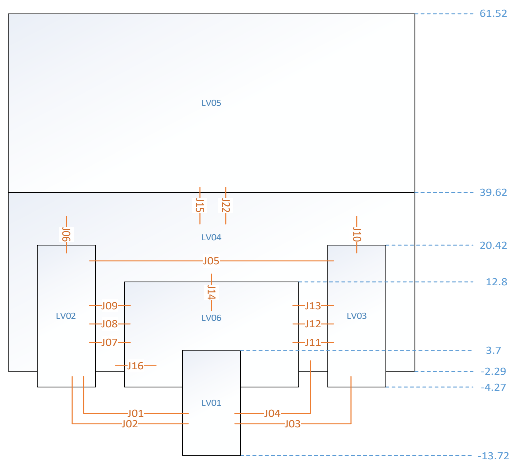

Fig. 2 SACAP containment model for OPR1000

A small break loss of coolant accident started with a break at cold leg with size of 0.002 m2 followed by failures of all active safety systems. It is assumed that operator actuates SDS 30 min after entry into SAMG, and IVI occurred 2 h after entry into SAMG [3].

The behaviors of the pressure and temperature in the containment are shown in Figs. 3and 4. We confirmed that the CINEMA BETA 2.0 results and MAAP5 results were similar.

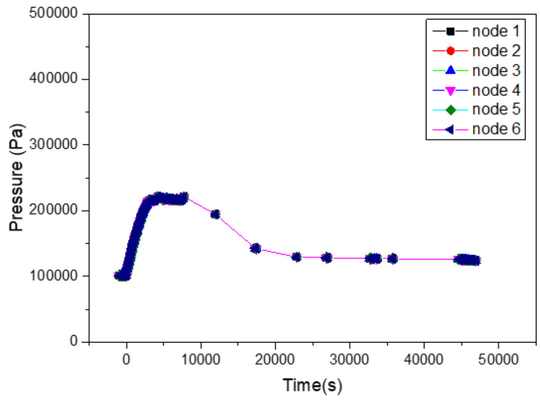

Fig. 3 Containment pressure results (CINEMA)

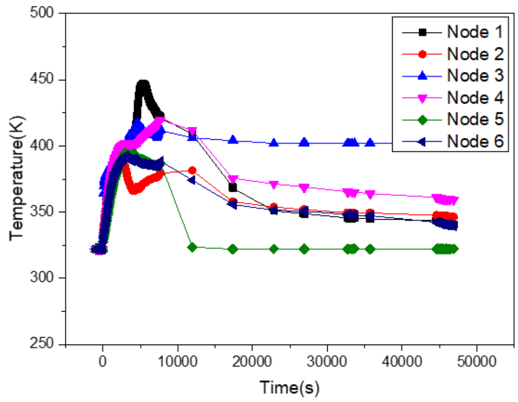

Fig. 4 Containment temperature results (CINEMA)

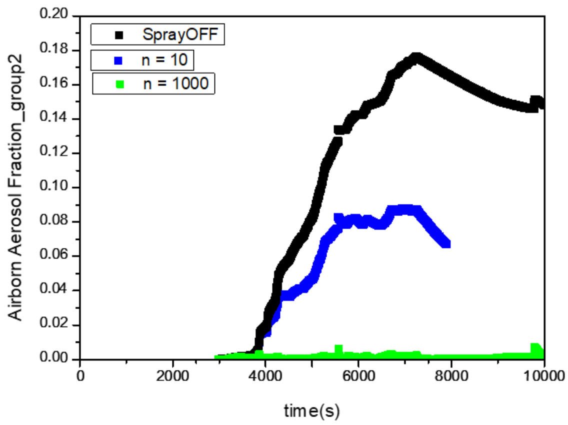

Fig. 5 Behavior of Group 2 (Iodine in the form of CsI) Aerosols (CINEMA)

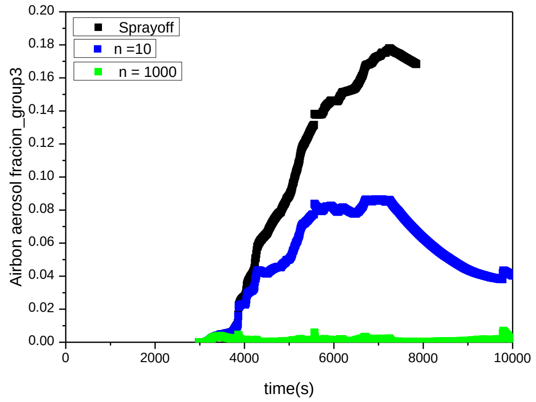

Fig. 6 Behavior of Group 3 (CsOH) Aerosols (CINEMA)

To investigate the effect of the filtration system, the preliminary analysis was performed assuming that the DF (Decontamination Factor) of filtration system was 10, 1000 under conditions where the spray was not operated. Also, it is assumed that when the hydrogen concentration is 1 % or more, the filtration system starts operating. Figures 5, 6 show the aerosol mass fraction variation in groups 2 and 3 in Table 1. The preliminary analysis was performed to qualitatively check the aerosol removal efficiency in the containment when the filtration systems are applied. It is confirmed that if the performance, capacity and number of filtration systems are well designed, a large amount of aerosol in the containment can be removed during the severe accident.

3. Conclusions

Before the passive radioactive filtration system development, it is necessary to confirm the fission product removal efficiency when applying the passive radioactive filtration system in the containment. We developed the fission product removal model by the developing system in SIRIUS code, and preliminary analysis was performed based on SLOCA scenario for the OPR1000 nuclear power plant. Thermal hydraulic results of CINEMA BETA 2.0 were verified with MAAP5. In addition, the changes in the concentration of fission products were analyzed when developing system was applied. It was confirmed that aerosols in the containment can be removed when the filtration systems are applied during the severe accident.

ACKNOWLEDGMENTS

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[2] J. Song et al. A comparative simulation of sever accident progressions by CINEMA and MAAP5, NED 404 (2023) 112181.
[3] J. Song et al. CSPACE for a simulation of core damage progression during severe accident, NED 53, 2021 3990-4002.