# A Modelling Status of Fission Product Behaviors in CINEMA Code

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## 1. Introduction

The amount of radionuclides released into the containment or to the environment is always the focus of the design, operation, and regulation of a nuclear power plant. In particular, a large amount of radioactive materials might be released if a core melt accident, that is, a severe accident, occurs in a nuclear power plant. Therefore, it is very important to estimate the behaviors of radioactive materials under the severe accident conditions.

The CINEMA (Code for INtegrated severe accident Evaluation and MAanagement) code has been developed since 2011 by a consortium of Korea Hydro and Nuclear Power, Korea Atomic Energy Research Institute, KEPCO E&C, and FNC technology. While sub-modules of CINEMA including CSPACE (Core meltdown, Safety and Performance Analysis CodE for nuclear power plants), SACAP (Severe Accident Containment Analysis Package), and SIRIUS (Simulation of Radionuclides Interaction Under Severe accidents) have been developed and improved independently, CINEMA was constructed by coupling of those submodules using MPI (Message Passing Interface) protocol [1]. SIRIUS module has been developed to predict the behaviors of the radioactive materials in the reactor coolant system and in the containment under severe accident conditions. SIRIUS consists of an estimation of the initial inventories, species release from the core, aerosol generation, gas transport, and aerosol transport. The final outcomes of the SIRIUS designate the radioactive gas and aerosol distribution in the reactor coolant system and in the containment.

The modelling status of SIRIUS are presented and the future plans for improving predictions of the radioactive behaviors are suggested.

## 2. A modelling status of SIRIUS

The transport phases of the radioactive materials during the severe accident can be divided into gas and aerosol. The gas and aerosol phases of the radioactive materials move through the reactor coolant systems and containments as loaded on the carrier gas or liquid, such as steam or water. Most radioactive materials might escape in the form of aerosols from a nuclear power plant during a severe reactor accident, and it is very important to predict the behavior of these radioactive aerosols in the reactor cooling system and in the containment building under severe accident conditions. Aerosols are designated as very small solid particles or liquid droplets suspended in a gas phase. The aerosol particles have little effect on the gas hydrodynamics, but the gas dynamics profoundly affect the behavior of the suspended particles. When there are continuing sources of aerosol to the gas phase or when there are complicated processes involving engineered safety features, much more complicated size distributions develop. Typical features of aerosol physics under reactor accident conditions that will affect the nature of the aerosols are (1) the formation of aerosol particles, (2) growth of aerosol particles, (3) shape of aerosol particles, (4) deposition of particles on the surfaces, and (5) a re-suspension of aerosol particles.

SIRIUS consists of an estimation of the initial inventories, species release from the core, aerosol generation, gas transport, and aerosol transport. The status of modellings in the SIRIUS are summarized in Table 1.

The initial inventories of the fission species in $UO_2$ such as Xe, Kr, Cs, I, Te, Sb, Se, Ba, Sr, Ru, Mo, La, and Zr (fission). are calculated based on general PWR and OPR1000. The other inventories that come from the structure materials, such as Zr, Fe, Cr, Ni, and Mn, are calculated from the masses of the cladding, stainless steel, and Inconel alloy.

Radioactive and nonradioactive species may be released from the core, cladding, structural materials such as stainless steel, and Inconel alloy if the materials heat up after gap releasing due to cladding failure. The species release rates are calculated using the CORSOR, CORSOR-M, and CORSOR-O models [2], which is a function of the material temperature. It is assumed that the released species from the core, classing, and structural materials are initially formed as representative groups of the gas phases. Each group has its own saturation gas pressure according to the temperature. Therefore, some amount of aerosols of each group may be generated if the gas pressure is higher than the saturation pressure, and some aerosols of each group may be evaporated into gas if the gas pressure is lower than the saturation pressure.

Table 1. Comparison of modelling status of SIRIUS in CINEMA

| Items | | CINEMA 1.0 | CINEMA 2.0 |
|---|---|---|---|
| Fission Product inventory | No. of species | 13 | 13 |
| | No. of group | 8 | 8 |
| Fission product release | No. of models on core release | 3 | 3 |
| | Model on fuel-cladding gap release | User defined / WASH-1400 | User defined / WASH-1400 |
| | Model on cavity release | N/A | N/A |
| Aerosol transportation/ deposition | Aerosol generation | O | O |
| | Aerosol mass / size | Total mass | Total mass / size |
| | Deposition mechanism | Gravitational settling, Impaction, Thermophoresis, Diffusiophoresis | Gravitational settling, Impaction, Thermophoresis, Diffusiophoresis |
| | Turbulent deposition | N/A | O |
| | Hygroscopic model | O | O |
| Iodine transportation | Iodine generation | N/A | N/A |
| | Iodine chemistry | N/A | N/A |
| Decay heat | Decay heat distribution | O | O |
| ESF | Aerosol pool scrubbing | N/A | O |
| | Elemental iodine pool scrubbing | N/A | N/A |
| | Organic iodine pool scrubbing | N/A | N/A |
| | Filters | N/A | O |
| | Sprays | N/A | O |
| V&V, QA | Verification &Validation | O(PHEBUS FPT3, ABCOVE) | O(PHEBUS FPT3, ABCOVE, RSE) |
| | QA/Documentation | O(Users, Design, V&V report) | O(Users, Design, V&V report) |

The gases and aerosols of fission products are transported through the reactor coolant systems and containments as loaded into the carrier gas or liquid such as steam or water. In SIRIUS, the aerosol transportation and deposition on the wall caused by sedimentation, impaction, thermophoresis, and diffusiophoresis mechanismscan be evaluated in each node. Aerosol eliminations by engineering safety features such as pool scrubbing, filters, and sprays are also modelled in SIRIUS.

All models in SIRUS are validated and vilified by using experimental data such as PHEBUS FPT3, ABCOVE, etc.

## 3. Conclusion and future works

A SIRIUS (Simulation of Radioactive nuclides Interaction Under Severe accidents) code was developed to predict the behaviors of the radioactive materials in a reactor coolant system and in the containment under severe accident conditions. SIRIUS consists of an estimation of the initial inventories, species release from the core, aerosol generation, gas transport, and aerosol transport. The individual modules of the SIRIUS code, such as calculation modules for aerosol generation, sedimentation, impaction, thermophoresis, diffusiophoresis, and wall deposition, have been verified by simulating various virtual problems and an ABCOVE experiment.

SIRIUS has been updating by adding some models related to the fission product releasing model from fuel (CORSOR-BOOTH), aerosol suspension, iodine pool chemistry, etc.

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