Transactions of the Korean Nuclear Society Spring Meeting
JeJu, Korea, May 18-23, 2009

Development of Aerosol Behavior Analysis Module for GAMMA+

Jun Soo Yoo*, Nam il Tak , Hong Sik Lim

Korea Atomic Energy Research Institute, DukJin-dong 150-1, Yusong-gu, Daejeon

*Corresponding Author: yjs00@kaeri.re.kr

1. Introduction

Fission product (FP) generated by nuclear fission in VHTR can be released from small amount of inherently defective fuel during normal operation or by fuel damage under accident condition. Fission product released from various plant conditions is also mainly in a form of aerosol, which means suspensions of small solid or liquid particles in gases, except some gaseous radionuclide. Despite VHTR's improved safety features, considering potential risk such as possibility of fuel damage caused by graphite oxidation during air ingress accident, FP aerosol behavior needs to be understood better and modeled with considerable reliance in a safety analysis of VHTR. Completing that work properly, however, is not that simple because analysis of aerosol behavior includes various uncertainties resulting from many state variables, complex sub-models, and multiple spatial dimensions.

This paper deals with the application of the MAEROS model[1], which has been widely used for aerosol behavior analysis, as an independent module in GAMMA+[2], and verifies the validity of calculation results with simplified analytic solution as well as experimental data produced by Gwangju Institute of Science and Technology (GIST)[3]. Through this process, it could be found that how effectively the MAEROS model[1] in GAMMA+[2] simulates various phenomena regarding aerosol behaviors, and what the limitation of this analysis tool is.

2. General Characteristics of Aerosol Behavior Considered in VHTR

Leading mechanisms being considered for analysis of aerosol behavior in VHTR are not largely different from that of PWR except that hygroscopic phenomena can be neglected because there is no water in gas cooled reactor. Usually, aerosol particle populations are not stable but go through constant evolution as a consequence of new particle formation via nucleation process (homogeneous or heterogeneous), condensation and surface reactions on the particles, collisions amongst the particles which results in coagulation, and other various physical and chemical phenomena that occur within the particles. Aerosol particles can also be transported along a gas flow and experience changes in the surrounding physicochemical conditions, possibly under the influence of turbulence. Particle transport can also be affected by inertia, gravitation, and particle diffusion, as well as thermophoresis and other phoretic effects. Therefore, it is crucial to select and apply appropriate models based on various investigations in order to simulate aerosol behavior effectively with considerable accuracy. Main focus of this study will be limited to coagulation and deposition mechanism and its related models.

3. Verification with Simplified Analytic Solution

3.1 Simplified Analytic Solution

Analytic solution including coagulation and deposition mechanism for single-sized aerosol particles composed of single component can be simplified as following (Equation (1)). This can be derived based on basic equation describing the behavior of aerosols, which is a nonlinear, integro-differential equation of considerable complexity.

$$\frac{dN(t)}{dt} = -\gamma N(t)^2 - \kappa N(t) \qquad \text{------------- (1)}$$

First term represents the change rate of aerosol particle number caused by coagulation (γ : coagulation coefficient), and second term means the rate by deposition (κ : deposition coefficient). Analytic solution for Eq.(1) can be obtained as Eq.(2). This result was compared with GAMMA+[2] calculation to verify the MAEROS model[1] in it.

$$N(t) = \frac{\kappa N(0)}{(\nu N(0) + \kappa)e^{\kappa t} - \gamma N(0)} \qquad \text{------------- (2)}$$

3.2 Comparison with GAMMA+ Calculation

GAMMA+[2] calculation applying the MAEROS model[1] was performed under the same condition of Eq.(2) (i.e., single size, single component). In addition, it was tried to obtain GAMMA+[2] results considering only coagulation and deposition without the other mechanism such as condensation for comparison. Fig.1 shows that the result agrees perfectly with the analytic solution, Eq.(2).

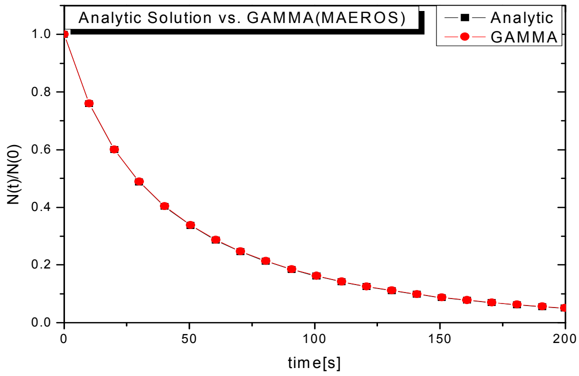

Figure 1. Analytic solution vs. GAMMA+ calculation result

4. Validation through Experimental Results

4.1 GIST experiment [3]

The nuclear aerosol experiment performed at GIST in 2002 was selected for validation of the MAEROS model[1] in GAMMA+[2]. Initial distribution of aerosol particles was assumed log-normal distribution based on experimental observances, and specific experimental case[3] which has a fan with 0-velocity inside test chamber was chosen to minimize the turbulence effect, which usually causes large uncertainty. Other parameters and conditions needed to perform calculation are of course defined same as experimental conditions.

4.2 Comparison with GAMMA+ Calculation

It is shown in Fig.2 that the peak of graphs moves right and down as time passes. It means the number of aerosol particles decreased and particle diameter increases as a result of coagulation and deposition. According to the experiment, this phenomenon would be clearer when initial particles exist more and are consisted of various sizes.

Fig.3 shows that the MAEROS model[1] in GAMMA+[2] predicts the experimental result[3] well when it comes to particle coagulation and deposition process. The error existed, however, could occur by uncertainty of several parameters such as coagulation shape factor, sticking efficiency, turbulence created when aerosol particles are initially injected. The MAEROS model[1] assumes complete spherical particle and 1.0 of sticking efficiency, which requires modification for reality. Particle distribution assumed in aerosol calculation influences the result significantly. Therefore, it would be important to use those values as reasonably as possible based on various investigations.

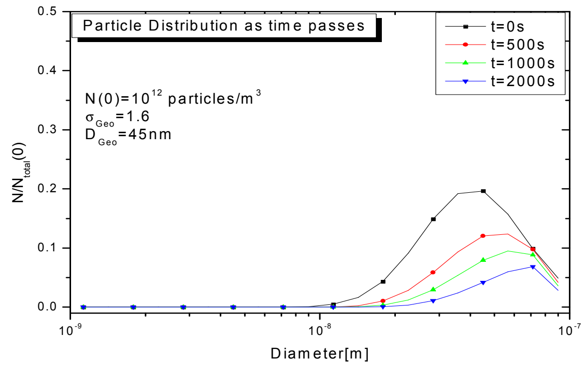

Figure 2. Aerosol particle size distribution as time passes

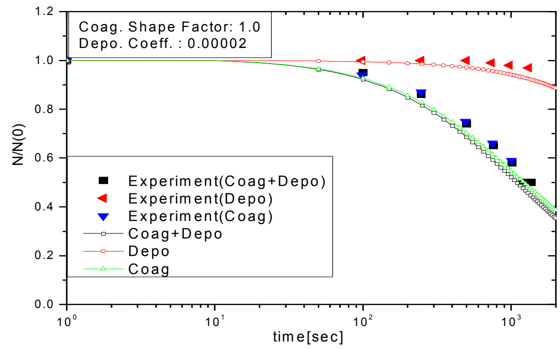

Figure 3. Experimental result vs. GAMMA calculation (N_0=10^{12}number/cm^3, σ_n=1.6, D_{g0}=115nm)

5. Conclusion

Throughout the verification with an analytic solution and validation against the experimental data[3], it was found that the MAEROS model[1] in GAMMA+[2] are well-defined numerically and predicts specific aerosol behavior including coagulation and deposition well. However, uncertainty estimation for some variables that was shown influential by this study is required for improving the reliability of simulation result. Also, additional work to consider a chemical process as well as an aerosol transport in a gas flow would be needed to cover various aerosol behaviors under actual plant conditions.

REFERENCES

[1] Gelbard, F., "MAEROS User Manual", NUREG/CR-1391, SAND80-0822, Sandia National Lab., 1982

[2] H. S. Lim, "GAMMA Multidimensional Multicomponent Mixture Analysis to Predict Air Ingress Phenomena in an HTGR", Nuclear Science Engineering, 152, 87-97, 2006

[3] K.W.Lee et.al "Validation of Aerosol Model for Nuclear Safety Analysis", Gwangju Institute of Science and Technology (GIST), Korea, 2002.