Verification and Validation of Aerosol Analysis Module in the MENTAS Code

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1. Introduction

A new computer code named MENTAS (Mechanistic Estimation of radioNuclide Transport with Aerosol Species) is under development in the Korea Atomic Energy Research Institute (KAERI). The MENTAS code is targeted for mechanistic calculations of radionuclide transport within reactor building of a high temperature gas-cooled reactor (HTGR). It is well-known that sizeable radionuclides in an HTGR are transported with the combination of aerosol particles such as graphite dust.

In this work, verification and validation studies have been carried out for the aerosol analysis module incorporated in the MENTAS code. At first, analytical solutions were used to verify the aerosol coagulation and deposition module. Then, validation studies were performed using two experimental tests (i.e., the Gwangju Institute of Science and Technology (GIST) experiment [1] and the ABCOVE (Aerosol Behavior Code Validation and Evaluation) test [2]).

2. Modeling of Aerosol Behavior

Fig. 1 shows the computer code system developed by KAERI to predict radionuclide release and transport in an HTGR [3-5]. The code system covers whole region of radionuclide transport from the nuclear fuel to environment. Among the computer codes shown in Fig. 1, the MENTAS code focuses on the radionuclide behavior within reactor building. One of important physical phenomena which occur during accident conditions within reactor building are aerosol processes that include aerosol coagulation and deposition.

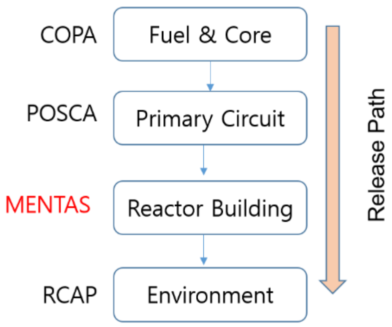

Fig. 1. Computer code system developed by KAERI for radionuclide release and transport in an HTGR.

In order to model the aerosol processes, the sectional method developed by Gelbard and Seinfeld [6] is adopted in the MENTAS code. The sectional method has been widely used for analyzing nuclear aerosol behavior during severe accident conditions in a light water reactor (LWR). The governing equation to describe the sectional method is as follows:

$$\frac{dQ_{l,k}}{dt} = \frac{1}{2}\sum_{i=1}^{l-1}\sum_{j=1}^{l-1}[{}^{1a}\beta_{i,j,l}Q_{j,k}Q_i + {}^{1b}\beta_{i,j,l}Q_{i,k}Q_j] - \sum_{i=1}^{l-1}[{}^{2a}\beta_{i,l}Q_iQ_{l,k} - {}^{2b}\beta_{i,l}Q_lQ_{i,k}] - \frac{1}{2}\,{}^{3}\beta_{l,l}Q_lQ_{l,k} - Q_{l,k}\sum_{i=l+1}^{m}{}^{4}\beta_{i,l}\,Q_i + S_{l,k} - R_{l,k} \quad (1)$$

where $Q_{l,k}$ = aerosol mass concentration of size group l, chemical component k, β = coagulation coefficient, S = source, and R = removal.

The coagulation model used in MENTAS treats three physical processes, i.e., particle Brownian motion, gravitational settling, and turbulent (turbulent shear and acceleration). For the deposition model, MENTAS considers three mechanisms, i.e., gravitational settling, diffusion, and thermophoresis. Additional deposition phenomena (such as inertial deposition) will be considered later.

3. Verification and Validation Results

3.1 Verification Using Analytic Solutions

With the assumptions of single chemical component (k=1), single section (l=m=1), and a simple removal expression (i.e., $R = \kappa Q$), Eq. (1) can be simplified as follows:

$$\frac{dQ}{dt} = -\frac{1}{2}\beta Q^2 + S - \kappa Q \quad (2)$$

Eq. (2) can be analytically solved for constant values of β and κ. Fig. 2 shows one of the verification results using analytic solutions of Eq. (2) without source (S=0). Excellent agreement is shown in the figure.

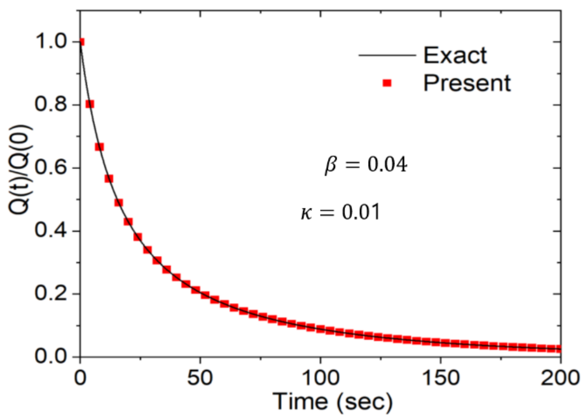

Fig. 2. Verification of aerosol coagulation and deposition module in MENTAS using analytical solution.

3.2 Validation Using GIST Experiment

The GIST performed an aerosol coagulation and deposition experiment using NaCl particles. Fig. 3 shows the experimental apparatus. The cylindrical test chamber was used. The height and diameter of the chamber were 60 and 60 cm, respectively. The particle size and its concentration were measured during the experiment.

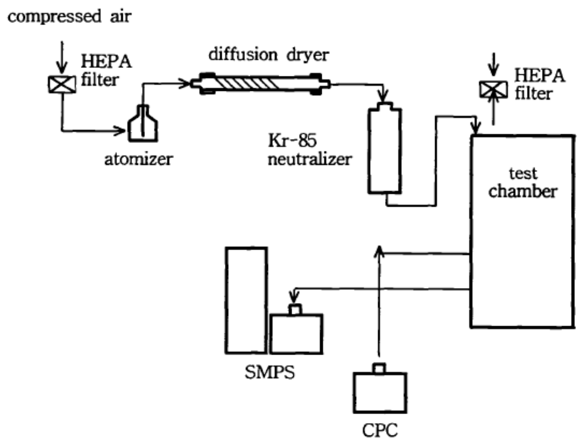

Fig. 3. Schematic of the GIST aerosol experiment [1].

Figs. 4 and 5 show the comparison of the calculated and measured values of the suspended NaCl particles. Good agreements are shown in the figures. The calculation results by MELCOR are added in the figures. The accuracy of the MENTAS is shown to be comparable to that of MELCOR.

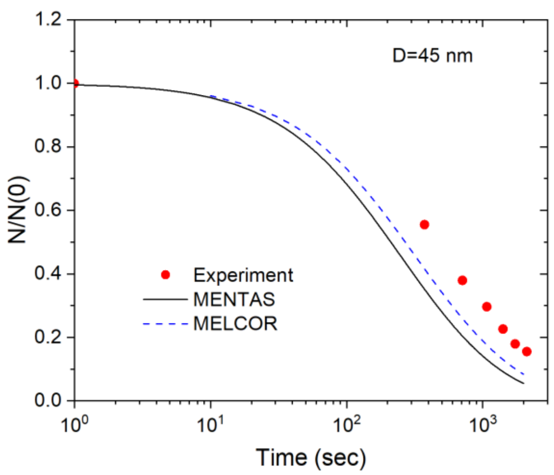

Fig. 4. Validation result of MENTAS using the GIST experiment (particle diameter = 45 nm).

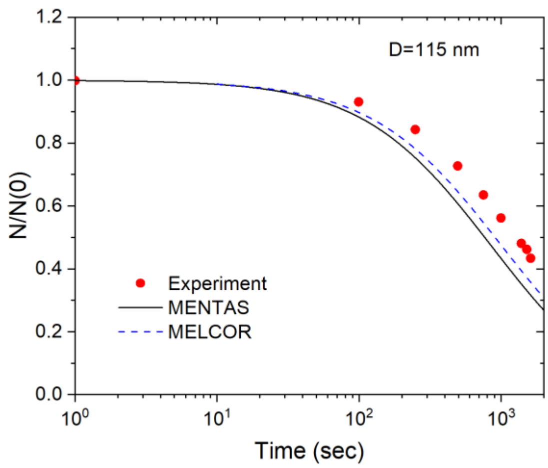

Fig. 5. Validation result of MENTAS using the GIST experiment (particle diameter = 115 nm).

3.3 Validation Using ABCOVE Test

Supported by U.S. DOE and U.S. NRC, a series of ABCOVE tests were performed using the Containment System Test Facility (CSTF) installed in Hanford Engineering Development Laboratory (HEDL). Among the ABCOVE tests, the AB-5 test was selected for the validation of the MENTAS code. During the AB-5 test, Na of 223 kg was injected during 872 seconds. The injected Na was transformed into aerosol particles (Na_2O_2 and NaOH) resulted by chemical reaction with the supplied oxygen.

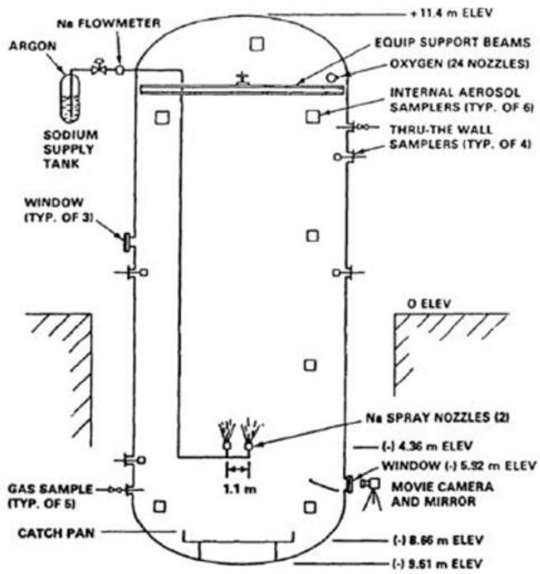

Fig. 6. Schematic of CSTF for the AB-5 test [2].

Figs. 7 and 8 show the validation results of MENTAS using the AB-5 test. They show that the calculated results by MENTAS are well agreed with the measured data. They also show that the accuracy of MENTAS is comparable to that of MELCOR in the prediction of AB-5 test data.

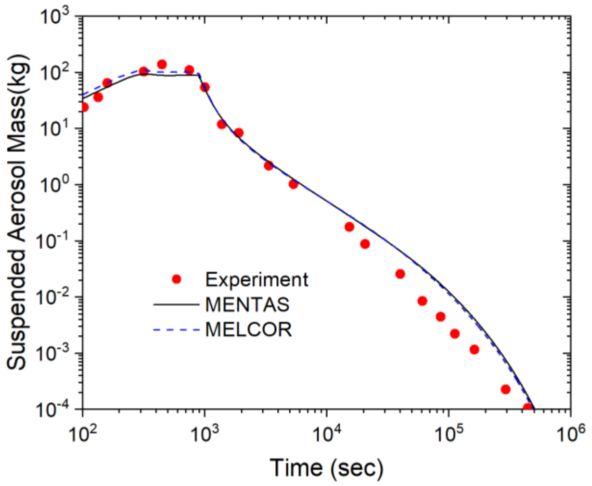

Fig. 7. Comparison of the calculated and measured suspended aerosol masses in the AB-5 test.

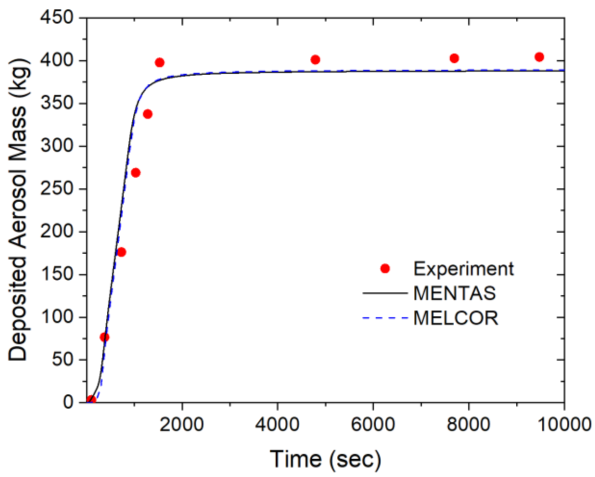

Fig. 8. Comparison of the calculated and measured aerosol deposition masses in the AB-5 test.

4. Conclusions

In this paper, verification and validation of the aerosol module in the MENTAS code were performed. At first, analytical solutions were used to verify the aerosol module. Then, the GIST experiment and the ABCOVE test were used for the validation. The results of the verification and validation studies show that the aerosol analysis module incorporated in the MENTAS code is highly reliable and reasonably accurate. Further researches are required for the verification and validation of aerosol transport including advection with a bulk gas flow.

Acknowledgements

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