Measurement of Aerosol Decontamination Factor Using Filters in AEOLUS Facilities

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1. Introduction

After Fukushima accident, countries around the world are tightening regulations to ensure that nuclear power plants are capable of coping with severe accidents. In Korea, nuclear safety act on severe accident were enacted in June 2016. The act requires that the accident probability with the amount of released Cs-137 greater than 100 TBq should be less than 1.0E-6/Ry. Minimizing the release of radioactive material during severe accident is essential not only to meet regulatory requirements, but also to minimize public health and environmental pollution. When a steam generator tube rupture (SGTR) accident occurs, fission products are released to the environment directly bypassing the containment. In this reason, it is important to evaluate the risk of SGTR accident to establish management procedures properly.

In order to evaluate the experimental results, the amount of aerosol removed inside the experimental setup in KAERI should be measured accurately. To know the aerosol decontamination factor inside the steam generator in various conditions during severe accident, single tube, tube bundle, single tube pool scrubbing, and tube bundle pool scrubbing experiments were performed. With the results, the aerosol removal rate inside the steam generator was evaluated conservatively.

2. Experimental Method

2.1 Experimental Setup

A schematic diagram of the steam generator aerosol decontamination test facility (AEOLUS, Aerosol Experiment on LWR under SGTR) is show in Figure 1. The main system of the test facility consists of an aerosol generator, a mixing chamber, a pressure container, and an aerosol sampling system. The aerosol is generated by mixing the aerosol fluid with carrier gas in the mixing chamber. The pressure vessel of AEOLUS is 0.6 m in diameter and 7.1 m in height, which is scaled down model of the SG in Korean NPP.

The auxiliary systems include the gas supply system consisting of steam generator, air compressor and liquid nitrogen facility, the cooling system consisting of the steam condenser, the cooling tower and the coolant pump, and the condensate storage and discharge system.

The aerosol sampling systems are connected to the exit of mixing chamber (upstream, S_U) and at the exit of SG vessel (downstream, S_D) are also connected either at the broken pipe exit (Nozzle, S_N) or in the vessel (Vessel, S_V). The sampling point was changed with purpose of experiment.

The signals of instruments (temperature, pressure, water level, flow rate, etc.) and the controls (valves) installed in AEOLUS facility are collected and processed through the data acquisition system (DAS) installed on the second and third floors of the LIFE building laboratory in KAERI. The DAS on each floor is then connected to the PCs in the control room via Ethernet.

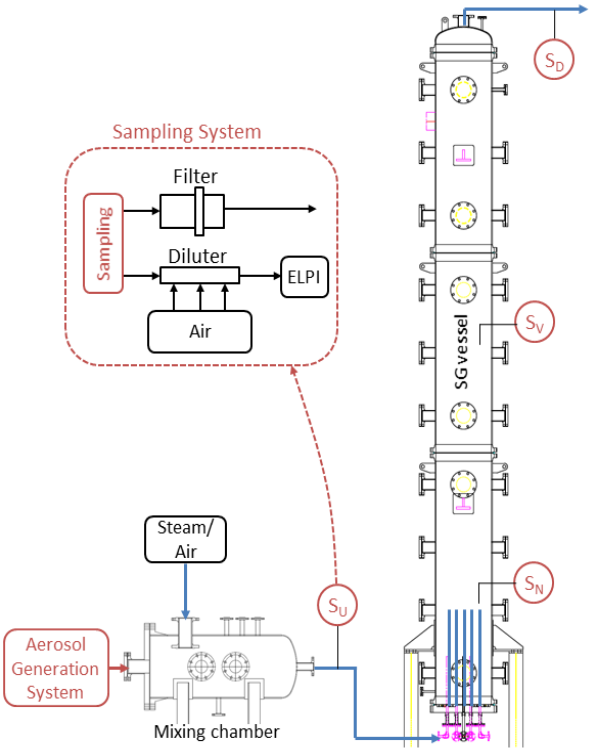


Figure 1. Schematic of AEOLUS Facility

2.2 Experimental Method

We performed the short tube single and the short tube bundle tests under dry and flooded conditions, respectively. The internal diameter of the sampling nozzle is 0.069 inches. It is recommended generally that the ratio of the sampling nozzle area to the pipe area becomes less than 0.05 to minimize disturbance of the main flow during sampling. In our case, the area of the sampling nozzle is 0.4% by 2 inch pipe reference for the

upstream and downstream, and approximately 2.8% by 3/4 inch pipe reference for the tube nozzle. The aerosol mixture used in the test is a mixture of SiO_2 particles of 0.7 micrometer of MMD and ethanol with a 10% mass concentration ratio. Therefore, glass fiber filters with large aerosol capture capacity were used to collect 0.7 micrometer of aerosol particles.

To measure aerosol mass using a filter, a filter assembly were prepared, requiring a pre-treatment process. The filter assembly consists of a filter, a gasket, a screen and a housing as shown in Figure 2. Before the test, dry condition of the filter, gasket and screen was made at oven of 110℃ during three hours. After that, the filter components were cooled down to room temperature using desiccator for more than two hours. Finally, we measured the weight using the microbalance that is shown in Figure 3. The measuring process was repeated and the average value was used for increasing reliability. To improve accuracy during weight measurement, the exposure time to environment was minimized. The humidity was also recorded on the measurement table. After the measurement finishes, the clean, pre-treatment components are mounted in the housing as shown in Figure 4. The filter assembly was then installed in the sampling system and a line heater was wrapped to prevent a possible steam condensation.

Figure 2. Filter Assembly Components

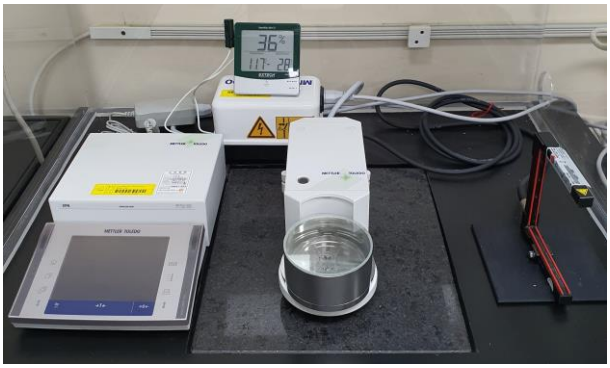


Figure 3. Micro Balance


Figure 4. Filter Assembly Order

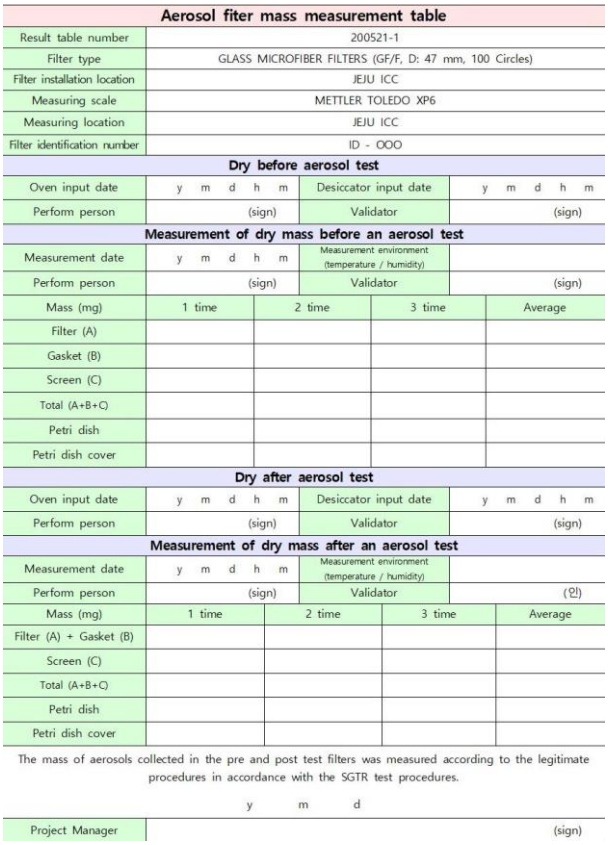
When the thermal hydraulic conditions of the experiment were satisfied, an aerosol mixture was injected into the aerosol storage tank in generating device to prepare for aerosol generation. The differential pressure between the tank containing aerosol mixture and the main system is set to be greater than 1 bar. Then, the aerosol generation was started and the aerosol sampling was also initiated at each sampling locations. The sampling time varies depending on the test conditions from 30 minutes to 1 hour.

At the end of the test, the filter assembly was detached from the sampling system and the components were disassembled. The filter, the gasket, and the screen are placed on a petri dish with known mass to measure the mass. If aerosols were deposited in the housing, we cleaned them with isopropyl alcohol on the petri dish, and measured the mass after evaporating the fluid. The petri dish specimens (filter, screen, gasket) were dried and cooled with the same procedure of the pre-treatment. After that, the mass of each component was measured using micro balance, which have accuracy of 0.005 mg.

The amount of aerosol collected is calculated as follows.

Total weight after testing (filter, gasket, screen, petri dish) - Total weight before testing (filter, gasket, screen, petri dish) = collected aerosol weight

The results of the measurements before and after the test are recorded on the form shown in Figure 5.



Aerosol fiter mass measurement table				
Result table number	200521-1			
Filter type	GLASS MICROFIBER FILTERS (GF/F, D: 47 mm, 100 Circles)			
Filter installation location	JEJU ICC			
Measuring scale	METTLER TOLEDO XP6			
Measuring location	JEJU ICC			
Filter identification number	ID - OOO			
Dry before aerosol test				
Oven input date	y m d h m	Desiccator input date	y m d h m	
Perform person	(sign)	Validator	(sign)	
Measurement of dry mass before an aerosol test				
Measurement date	y m d h m	Measurement environment (temperature / humidity)		
Perform person	(sign)	Validator	(sign)	
Mass (mg)	1 time	2 time	3 time	Average
Filter (A)				
Gasket (B)				
Screen (C)				
Total (A+B+C)				
Petri dish				
Petri dish cover				
Dry after aerosol test				
Oven input date	y m d h m	Desiccator input date	y m d h m	
Perform person	(sign)	Validator	(sign)	
Measurement of dry mass after an aerosol test				
Measurement date	y m d h m	Measurement environment (temperature / humidity)		
Perform person	(sign)	Validator	(인)	
Mass (mg)	1 time	2 time	3 time	Average
Filter (A) + Gasket (B)				
Screen (C)				
Total (A+B+C)				
Petri dish				
Petri dish cover				
The mass of aerosols collected in the pre and post test filters was measured according to the legitimate procedures in accordance with the SGTR test procedures.				
y m d				
Project Manager	(sign)			

Figure 5. Aerosol Filter Mass Measurement Table

3. Results and Discussions

The decontamination factor were calculated by measuring the amount of aerosols collected at each sampling position. An isokinetic sampling are preferred for aerosol sampling at each sampling position, however, it is sometimes not practical due to the insufficient differential pressure for the isokinetic sampling flow. In those cases, the concentrations were corrected using the ratio of the isokinetic condition and the actual sample rate using the equation as follows

$$\frac{C}{C_0} = 1 + \left(\frac{U_0}{U} - 1\right)\left(1 - \frac{1}{1 + (2 + 0.62U/U_0)Stk}\right)$$

where C is the concentration of aerosols, U is the speed, and Stk is the Stoke's number defined by the diameter of the sampling nozzle and U_0. The subscript 0 indicates the isokinetic condition.

Tables 1 to Table 4 shows the results of aerosol decontamination tests with single tube and short tube bundle under dry and flooded conditions. The tables show the results of aerosol concentration, which is the aerosol mass collected at the filter divided by the volume of air inhaled during the sampling. The tables also include the calculation of the isokinetic condition and the correlation ratio calculation due to the difference between the actual sample flow measured by mass flow controller (MFC). Also, the decontamination factor of the test were calculated by comparing the concentrations at the upstream and that the downstream.

Table 1. Results of Short Tube Bundle Dry Test

		Upstream	Downstream
Aerosol Density	Time (s)	1800	1800
	Actual flow (lpm)	11.0	11.0
	Vol. of Air (m^3)	0.3297	0.32952
	Aerosol mass (mg)	123.376	27.566
	Density (C0, mg/m^3)	374.207	83.655
	Concentration Ratio	0.996	0.990
	Density (C, mg/m^3)	375.653	84.529
DF			**4.1**

Table 2. Results of Short Tube Bundle Flooded Test

		Upstream	Downstream
Aerosol Density	Time (s)	1800	1800
	Actual flow (lpm)	11.0	11.0
	Vol. of Air (m^3)	0.32967	0.302703
	Aerosol mass (mg)	125.436	0.565
	Density (C0, mg/m^3)	380.490	1.867
	Concentration Ratio	0.997	1.007
	Density (C, mg/m^3)	381.749	1.854
DF			**191.0**

Table 3. Results of Short Tube Single Dry Test

		Upstream	Downstream
Aerosol Density	Time (s)	1200	1200
	Actual flow (lpm)	11.6	11.4
	Vol. of Air (m^3)	0.23158	0.22886
	Aerosol mass (mg)	101.09	12.418
	Density (C0, mg/m^3)	436.523	54.260
	Concentration Ratio	0.999	0.999
	Density (C, mg/m^3)	437.007	54.288
DF			**8.0**

Table 4. Results of Short Tube Single Flooded Test

		Upstream	Downstream
Aerosol Density	Time (s)	3600	3600
	Actual flow (lpm)	11.0	11.0
	Vol. of Air (m^3)	0.66	0.66
	Aerosol mass (mg)	136.645	1.746
	Density (C0, mg/m^3)	207.038	2.645
	Concentration Ratio	1.000	1.000
	Density (C, mg/m^3)	207.023	2.645
DF			**78.3**

4. Conclusions

We described the detailed procedures of aerosol measurement by using filter to estimate the decontamination factor in steam generator. The aerosol was generated in the mixing chamber by ejecting the aerosol fluid with carrier gas, and then collected the dispersed aerosol in several places to calculate the aerosol concentration of them. The decontamination factors were then evaluated by comparing the aerosol concentration at each position. In the short tube bundle dry test, the decontamination factor was estimated to be about 4. In the flooded test, the decontamination factor was estimated to be about 191. In the short tube single dry test, the decontamination factor was estimated to be about 8. In the flooded test, the decontamination factor was estimated to be about 78. The results of the above experiment show that the decontamination factor increases significantly in flooded conditions. You can also see that the decontamination factor increases if there is a structure, such as a bundle of tubes around the break. This is originated from the inertial impaction of aerosol to other structures. One interest finding is that structures could be helpful to remove aerosol though there is a pool scrubbing effect with water pool.

The integral tests of aerosol decontamination in SG including the effects of separator and dryer have been performing, and the overall map of aerosol removal in SG under various conditions are still on going.

ACKNOWLEDGEMENT

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