From Lab to Pilot-scale System for Filter Performance Test to Remove Radioactive Aerosol from Decommissioning of Nuclear Power Plant

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1. Introduction

The dismantling process of nuclear power plants (NPPs) requires the disposal of large amounts of radioactive materials. In particular, a cutting process is essential for decontamination and volume reduction of radioactive materials but results in the release of a large number of radioactive aerosols [1, 2].

Although the external leakage of radioactive aerosol is suppressed as much as possible by using an air cleaning system installed in the NPPs, additional efforts are needed to reduce the risk of internal exposure of workers to the high concentration of radioactive aerosol. For this reason, we are developing a modular design-based mobile air-cleaning unit (mobile ACU). The mobile ACU consists of a filter module, an adsorber module, and a control & monitoring module. The filter module includes various filters such as a bag filter, a metal filter, and a HEPA filter. The mobile ACU has the advantage of being able to move freely even a complex and narrow site in NPPs. Mobile ACUs can reduce indoor air pollutants concentrations such as radioactive aerosol and harmful gases (NOx, SOx, CO, etc.)

In this study, we introduce test facilities and experimental processes from Lab to Pilot-scale to evaluate the aerosol removal performance of filters used in mobile ACU.

2. Experimental system

2.1. Lab-scale filtration test for filter unit

The lab-scale test is an aerosol removal performance test for three different types of filters (HEPA, metal, and bag filter) used in filter modules. Aerosol generated when dismantling a nuclear power plant was simulated through plasma metal cutting in a metal chamber. Non-radiative metals were used because heat or radiation resistance were not considered in this experiment.

A SUS304 metal plate was automatically cut using a plasma cutter (Powermax125, Hypertherm) mounted inside the chamber (dimensions: 1.3 m(W) x 1 m(L) x 0.66 m(H)) (Table. 1). The generated aerosol moves to the test filter by the flow of the blower [3]. Two high-resolution aerosol detectors (HR-ELPI+, Dekati) units were used simultaneously for aerosol measurement equipment, and a dilutor (eDilutor, Dekati) was installed at the front end of the measurement equipment according to the concentration range.

The HEPA and metal filters have a rectangular parallelepiped shape, while the bag filter has a cylinder shape. A filter case suitable for each type of test filter was manufactured and fastened (Fig. 1 and Fig. 2).

Table 1. Operating condition of plasma cutting.

Filter Type	Metal sample	Plasma Arc Current	Nozzle to Work Distance	Cutting Speed	Cutting Length
HEPA	SUS304 plate (10 mm)	125 A	10 mm	1 cm/s	10 cm
Metal					
Bag					5 cm

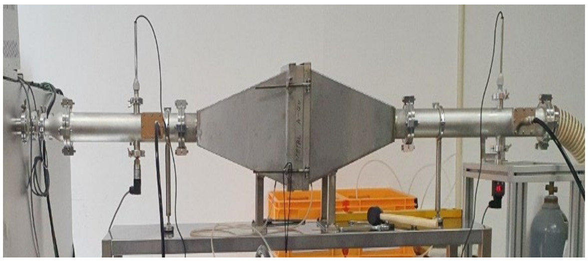

Fig. 1. Configuration of HEPA filter and metal filter performance test.

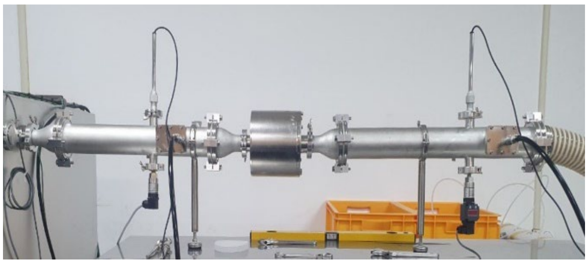

Fig. 2. Configuration of bag filter performance test.

2.2. Pilot-scale filtration test for proto-type mobile ACU

Pilot-scale filtration test was conducted in a shielding room with dimensions of 3 m(W) x 3 m(L) x 3 m(H). The test used a proto-type mobile ACU which consists of a filter module, a control & monitoring module, and a fan module (750 cfm) (Fig. 3). The filter module includes a series of bag filter, metal filter, and HEPA filter.

The metal filter and HEPA filter are installed in one single housing (dimensions: 0.6 m(W) x 0.6 m(L) x 1 m(H)). The bag filter is installed in the other housing located in front of the metal/HEPA filter housing. Each module has four wheels which make it easier to be moved freely. And it can be assembled in a workspace using a flexible tube.

Aerosols are continuously supplied to the shielding room using a brush-type dust generator (RBG2000D, PALAS) that generates test aerosols from powders. Fe_3O_4 powder having a size of 0.3 μm was selected to simulate the metal cutting process (Fig. 4). The generation mass flow of Fe_3O_4 aerosol is 5.58 g/min. In the same way as the Lab-scale experiment, aerosol measurements were performed at the inlet and outlet of the filter module using HR-ELPI+.

Fig. 3. Proto-type mobile ACU.

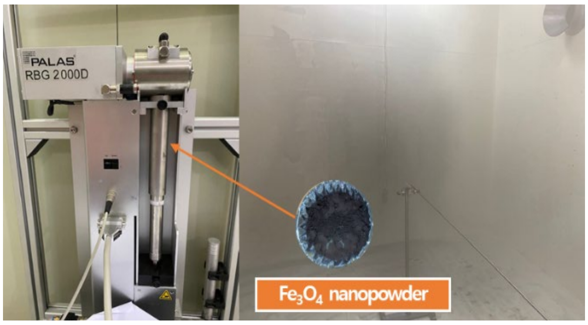

Fig. 4. Fe_3O_4 aerosol generation in the shielding room.

2.3. Test filter

Three types of filters were used in the experiment: HEPA filter, metal filter, and bag filter. Depending on the experiments, the size of the filter is different, and the details are shown in Table 2.

Table 2. Specification of test filters.

Filter Type	Dimension (mm)		Filter Media	Design Criteria
	Lab-scale	Pilot-scale		
HEPA	305(W) 305(H) 150(D)	610(W) 610(H) 150(D)	Glass Fiber	99.97% at 0.3 μm
Metal	305(W) 305(H) 50(D)	610(W) 610(H) 50(D)	Stainless wire	80% at 5~10 μm
Bag	120(OD) 100(L) (1ea)	145(OD) 500(L) (4ea)	Synthetic (Anti-Static Coating)	90% at 5~10 μm

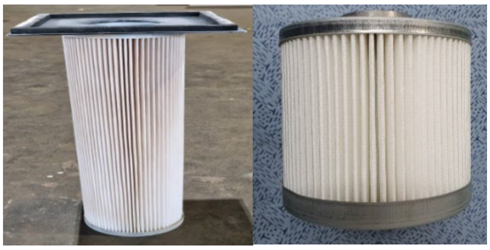

Fig. 5. Bag filter for the pilot-scale test (Left) and the for lab-scale test (Right).

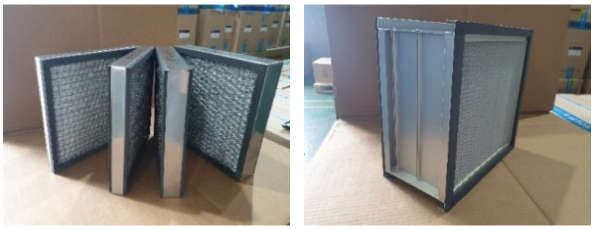

Fig. 6. (Left) Metal filter, (Right) HEPA filter.

2.4. Filter efficiency calculation

The aerosol removal efficiency of each filter (η) is determined by following equation 1 [4]:

$$\eta(\%) = \left(1 - \frac{C_d - C_{b,d}}{C_u - C_{b,u}}\right) \times 100 \qquad (1)$$

Where C_u is the concentration of upstream particles; C_d is the concentration of downstream particles; $C_{b,u}$ is the background level aerosol concentration of upstream particles; $C_{b,d}$ is the background level aerosol concentration of downstream particles; The unit of concentration of particle is particle number per cubic-centimeter (#/cm^3).

3. Results and Discussion

The aerosol removal efficiency of HEPA filter above 99.97% is achieved in 0.006~10 μm sized region. Also, the Bag filter efficiency exceeded the reference value of 80%, reaching 99.98% (Table 3). However, the aerosol removal performance of the metal filter did not satisfy the reference value of 80% in a region of 5 ~10 μm. Therefore, we focused on the increasing efficiency of the metal filter equipped on the pro-type mobile ACU. The aerosol removal performance of the proto-type mobile ACU verified by the pilot-scale filtration test is 99.99% or higher, and the maximum penetration particle size is confirmed in the 9 μm region (Fig. 7).

Table 3. Aerosol removal efficiency at the different particles size ranges.

Test		Aerosol Removal Efficiency in size range		
		0.006~10 μm	0.3~1 μm	5 ~10 μm
Lab-Scale	HEPA	99.985%	99.999%	99.999%
	Metal	61.293%	64.506%	73.403%
	Bag	99.973%	99.993%	99.982%

Pilot-scale	Proto-type	99.998%	99.999%	99.998%

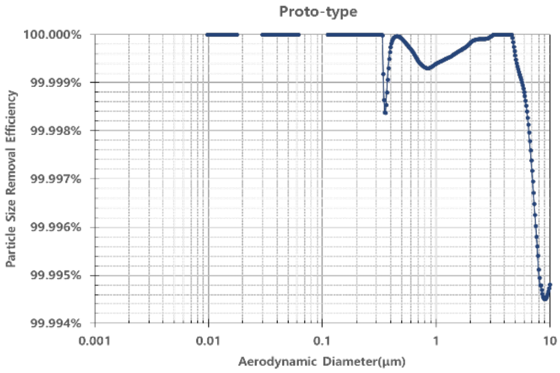

Fig. 7. Aerosol removal efficiency versus aerosol size for proto-type mobile ACU.

Table 3 shows that the most of aerosols are removed by the HEPA filter. However, based on this result, it is not possible to say that bag filters or metal filters are not needed. Increasing dust-loading inside a filter could cause an increase in pressure drop. Therefore, a filter that has a high-pressure drop should be replaced by a new one for avoiding filter rupture. The bag filter and metal filter are used as a pre-filter which can increase the HEPA filter lifetime. The mobile ACU is also designed to selectively utilize the use of pre-filters depending on the concentration of aerosol generation.

4. Conclusion

The purpose of this study is to design and apply an air cleaning system to protect workers during the dismantling of NPPs. To accomplish its objectives, the efficiency of the HEPA filter, metal filter, and bag filter, which are representative filters for aerosol removal, was evaluated through lab-scale experiments. Based on these results, the prototype mobile ACU was designed, and the aerosol removal performance of the prototype was satisfied with design criteria through pilot-scale experiments. Afterward, it plans to confirm the aerosol removal performance through on-site metal cutting experiments.

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