Performance of Modular Design-based Mobile Air-cleaning Unit for Removing Radioactive Aerosol from Decommissioning of Nuclear Power Plant

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1. Introduction

The decommissioning of nuclear power plants can cause large amounts of radioactive aerosols due to radioactive contamination or activated metal cutting [1]. The radioactive aerosols are inhaled into the human respiratory system causing serious radiation internal exposure. For this reason, an air supply and exhaust purification system for preventing leakage of radioactive materials and exposure to workers should be needed during both the operation of nuclear power plants and the decommissioning process [2, 3]. However, during decommissioning, it may be difficult for the existing HVAC system to operate due to power loss or the occurrence of new contaminated areas. To solve this problem, there is a need for a new air cleaning device that is easy to move and install.

For this reason, we are developing a modular design-based mobile air-cleaning unit (mobile ACU). The mobile ACU includes the pre-filters (bag filter and metal filter) and a HEPA filter. The HEPA filter, which is a major component of air purification system, is essential for the containment of radioactive aerosols. However, HEPA filter has operating restrictions on the temperature, humidity, and flow rate [4]. It also has the disadvantage of being treated as radioactive waste that is difficult to recycle. It was confirmed that when the pre-filter was used, the lifespan of the HEPA filter was increased by about 2 times or more [5]. By increasing the replacement cycle of the HEPA filter without filter efficiency decreased, it is possible to obtain the effect of reducing radioactive waste. In this study, we introduce field test facilities and experimental processes to evaluate the aerosol removal performance of filters used in mobile ACU.

2. Experimental system

2.1. Specification of ACU

The test used a proto-type mobile ACU which consists of a filter module, a control & monitoring module, and a fan module (500~1,000 cfm) (Fig. 1). The filter module includes a series of bag filter, metal filter, and HEPA filter.

Fig. 1. Proto-type mobile ACU.

Each filter is installed in a single housing and the housing is designed to be as small as possible for better mobility (dimensions: 1 m(W) x 0.75 m(L) x 1.2 m(H)). The filter housing is designed so that each filter module can be attached and removed as needed. Three types of filters were used in the experiment: HEPA filter, metal filter, and bag filter (Table 1, Fig. 2)

Table 1. Specification of test filters.

Filter Type	Dimension (mm)	Filter Media	Design Criteria
HEPA	610(W) 610(H) 292(D)	Glass Fiber	99.97% at 0.3 μm
Metal	610(W) 610(H) 50(D)	Stainless wire	80% at 5~10 μm
Bag	220(OD) 300(L) (4ea)	Synthetic (Anti-Static Coating)	80% at 5~10 μm

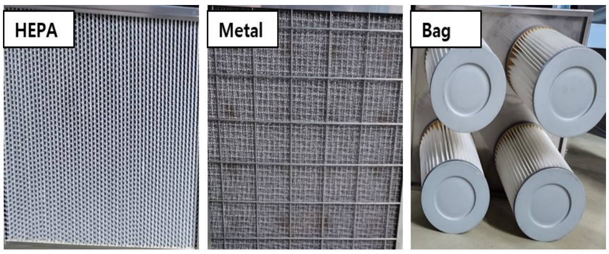

Fig. 2. Test filters installed in mobile ACU

2.2. ACU filtration test in metal cutting facilities

The aerosol removal efficiency of mobile ACU when cutting an actual metal specimen. A metal cutting was performed in a work tent equipped with a plasma torch cutter and an oxy-fuel cutter in Busan Machinery Research Center, Korea Institute of Machinery and Materials. The filtration test was conducted in a shielding tent with dimensions of 5.0 m(W) x 5.0 m(L) x 2.3 m(H) (Fig. 3).

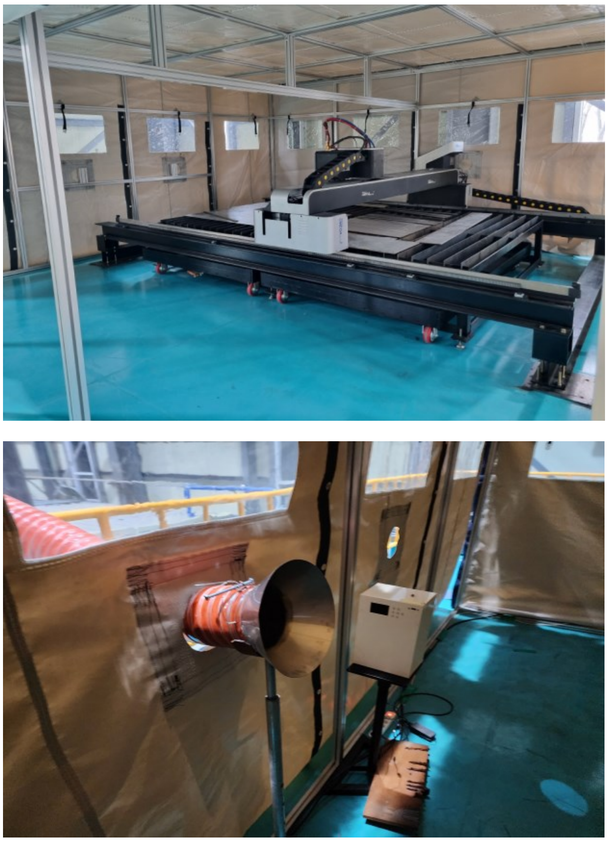

Fig. 3. Work tent equipped with mobile ACU inlet

A plasma torch (Powermax 85, Hypertherm) and Oxy-fuel cutter installed in CNC table was used for metal cutting.

Fig. 4. A plasma torch cutter and an oxy-fuel cutter in Busan Machinery Research Center.

The metal specimen are stainless steel plate (SUS304) and carbon steel plate (SS400) with 20mm thickness. However, due to the physical properties of stainless-steel plates, stainless steel is not cut by oxy-fuel cutting. The cutting condition for each cutting method selected that was expected to produce the most aerosol generation based on prior experience (high plasma current, high gas pressure, and low cutting speed). The concentration of aerosol generation in the test conditions was controlled by setting the cutting length differently (250mm and 500mm).

2.3. Filter efficiency calculation

Two high-resolution aerosol detectors (HR-ELPI+, Dekati) units were used simultaneously for aerosol measurement equipment and connected to the sampling ports on both the upstream and downstream sides of the mobile ACU. The aerosol removal efficiency of each filter (η) is determined by following equation 1:

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

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 mobile ACU above 99.97% (the design criteria of HEPA filter) is achieved in 0.3~10 μm sized region (Table 2). However, the filtration efficiency in 0.006~10 μm sized region is decreased up to 97.18%. This is judged to be the influence of nano-aerosol generated during metal cutting.

Fig. 5 shows the change in aerosol concentration in the tent before and after using the Mobile ACU, it decreases to the background concentration within 30 minutes after cutting when using the Mobile ACU, while it takes a lot of time if not installed. This is the basis that Mobile ACU can reduce the concentration of radioactive aerosol in contaminated space or room.

Table 2. Aerosol removal efficiency at the different particles size ranges.

Cutting tool	Cutting length (mm)	Aerosol removal efficiency in size range (%)			
		0.006~10 μm	0.3~1 μm	1 ~3 μm	3 ~10 μm
Plasma (SUS304)	250	99.92915	99.99997	100.00000	99.99994
	500	97.17863	99.99991	100.00000	99.99989
Plasma (SS400)	250	99.99905	100.00000	99.99998	99.99996
	500	98.99005	99.99973	99.99997	99.99999
Oxy-fuel (SS400)	250	99.86458	99.99885	100.00000	100.00000
	500	99.97889	100.00000	99.99995	99.99993

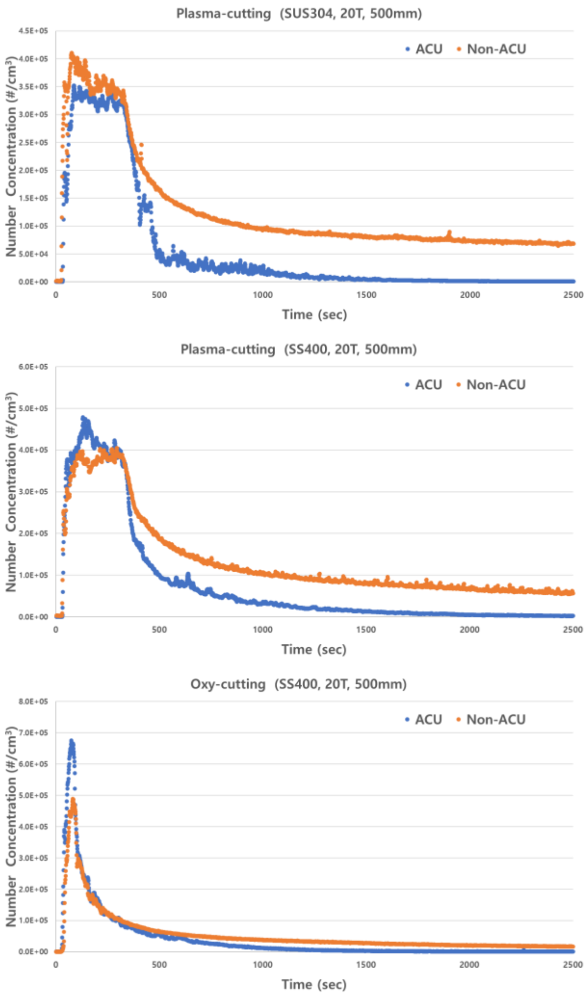

Fig. 5. Changes in aerosol concentration due to installation of mobile ACU

4. Conclusion

The purpose of this study is to design and apply mobile ACU for removing radioactive aerosol during dismantling of NPPs. The aerosol removal performance of the mobile ACU was satisfied with design criteria through on-site metal cutting experiments. Currently, general industries including nuclear facilities use air purification system with HEPA filters for the safety of workers. In particular, the replacement cycle of the HEPA filter may be shortened in a high-concentration aerosol environment generated during the decommissioning of nuclear facilities. The pre-filter can be used to extend the life of the HEPA filter.

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REFERENCES

[1] Y. Oki, M. Numajiri, T. Suzuki, Y. Kanda, T. Miura, K. Iijima, and K. Kondo, Particle size and fuming rate of radioactive aerosols generated during the heat cutting of activated metals, Applied radiation and isotopes, Vol. 45, pp. 553-562, 1994.

[2] N. Chae, MH Lee, S. Choi, B. Park, and J. Song, Aerodynamic diameter and radioactivity distributions of radioactive aerosols from activated metals cutting for nuclear power plant decommissioning, J. Hazardous Mat., Vol. 369, pp. 727-745, 2019.

[3] MH. Lee, W. Yang, N. Chae, and S. Choi, Performance assessment of HEPA filter against radioactive aerosols from metal cutting during nuclear decommissioning, Nuclear Engineering and Technology, Vol. 52, no. 5, pp. 1043–1050, 2020.

[4] Y Ryu, K. Kim,.K. Kil, 2001. The characteristics of HEPA filter and its handling technology, KAERI/TR-1982/2001.

[5] NRC, 2001. Design, Testing, and Maintenance Criteria for Atmosphere Cleanup System Air-Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants. Regulatory Guide 1.5. Rev.3. Washington, DC.