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Aerosol Analysis System for Internal Dose Assessment of Worker's Internal Dose in D&D

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1. Introduction

Radioactive aerosols could be the dominant contributors to the internal dose of workers during the decommissioning and decontamination (D&D) of nuclear power plants (NPPs). For disposing the radioactive waste from the D&D activities, large amounts of radioactive metal should be cut into small pieces for loading into disposal containers. These activities produce airborne species called radioactive aerosols that worker should caution not to inhale [1].

The deposition of aerosol particles into the respiratory tract can be varied according to aerodynamic diameter distribution. Also, the adsorbed aerosol can be moved from lung tissue to blood vessel depending on their chemical properties. Therefore, the internal dose of the worker from radioactive aerosols is affected by the characteristics of the aerosol such as aerodynamic diameters distribution, radioactive isotopes, and chemical forms [2].

However, the previous studies for radioactive aerosol had some limitations that they did not verify the reproducibility of experiment and chemical properties of aerosol. In this study, we investigated the factors affecting workers' internal exposures and established the aerosol analysis system for capturing aerosols that occur during actual metal cutting.

2. Methods and Experimental system

2.1. Aerosol collecting and measurement system

One of the most important physical characteristics of aerosols is the aerodynamic diameter distribution. In order to measure the aerodynamic diameter commonly used a cascade impactor. However, a typical cascade impactor has a significant drawback that the particles under 0.3 μm range cannot be measured. Hence, we selected high-resolution ELPI+ (HR-ELPI+, Dekati Ltd) that can analyses particles down to 6 nm size as a measurement instrument in our system (Fig. 1). The collection substrates are placed on each impactor stage for chemical analyzing.

Fig. 1. The real-time aerodynamic diameter (range: 6 nm- 10 μm) distribution was measured by the HR-ELPI+ (Dekati).

The aerosol measurement system in KAIST Nuclear Fuel Cycle laboratory (Fig. 2) had been composed of a plasma arc torch (powermax125, Hypertherm), an aerosol chamber, and a servo-motor system. The ventilation pipe was designed to avoid the loss of particle in the bending point.

Fig. 2. The aerosol measurement system in KAIST Nuclear Fuel Cycle laboratory.

2.2. A stainless-steel cutting by plasma arc torch

Stainless steel 304L is used in various components of the NPP due to its high corrosion resistance. The stainless steel with 10 mm thickness was cut using the plasma arc at a constant speed of 0.5 m/sec (Fig 3). For reproducible experiments, a metal plate was automatically controlled by servo motors and the plasma arc torch is fixed to the top of the chamber.

Fig. 3. The stainless-steel cutting with the plasma arc torch

2.3. Chemical analysis for aerosol using ICP-OES

To determine the mass of the metallic element at each particle size range, the aerosol collection substrate was dissolved in an acid solution. The diluted solution which contains the aerosol was determined by inductively coupled plasma spectrophotometer (ICP-OES).

The ICP-OES (Agilent ICP-OES 5110) in KAIST analysis center for research advancement (KARA) was used to measure the concentration of metallic elements up to 10^{-8} (ppb) level. The unique characteristic wavelength of each element emitted is separated by a spectrometer and measured with the detector the intensity to determine the element concentration in the specimen.

3. Results and Discussion

3.1. The general formulations for inhalation dose estimation

The general formulations for inhalation dose estimation are described in the following equations [3]:

$$I = \frac{C_{air} \times \text{Breathing Rate} \times \text{Time}}{\text{Respiratory Protection Factor}} \qquad (1)$$

Where I is inhalation intake of radionuclides [Bq], C_air is airborne radionuclide concentration [Bq/m3]. The breathing rate is a constant value which is an average breathing rate of worker (1.2 m^3/h) given in ICRP 66 publication.

$$Inhalation\ Dose = \sum_i I_i \times D_i \qquad (2)$$

where i is type of the radionuclide, D_i is inhalation dose coefficient for radionuclide i [Sv/Bq].

For the assessment of worker's internal exposure to radioactive aerosols, it is important to understand the characteristics of radioactive aerosols such as aerodynamic diameters, radioisotopes of the element, and chemical forms. Most abundant radionuclides in the stainless steel of a PWR reactor pressure vessel are ^{55}Fe, ^{59}Ni, ^{63}Ni, ^{51}Cr, ^{58}Co, and ^{60}Co (Table 1).

Table. 1. Inhalation dose coefficient of each nuclide [4].

Nuclide	Inhalation			
	Type	f_1	e (Sv/Bq) AMAD* 1μm	e (Sv/Bq) AMAD 5μm
Co-60	M	0.1	9.6E-9	7.1E-9
	S	0.05	2.9E-8	1.7E-8
Co-58	M	0.1	1.5E-9	1.4E-9
	S	0.05	2.0E-9	1.7E-9
Ni-59	M	0.05	1.8E-10	2.2E-10
	S	0.05	1.3E-10	9.4E-11
Ni-63	M	0.05	4.4E-10	5.2E-10
	S	0.05	4.4E-10	3.1E-10
Fe-55	F	0.1	7.7E-10	9.2E-10
	M	0.1	3.7E-10	3.3E-10
Cr-51	F	0.1	2.1E-11	3.0E-11
	M	0.1	3.1E-11	3.4E-11
	S	0.1	3.6E-11	3.6E-11

*AMAD is a physical parameter which fifty percent of the activity in the cumulative size distribution.

Inhalation dose coefficient for a radionuclide is determined by the absorption type and the activity median aerodynamic diameter (AMAD. The chemical form of the radionuclide is a key parameter in establishing absorption type. According to the ICRP recommendation, the solubility of inhaled materials is classified into Fast (Type F), Moderate (Type M) and Slow (Type S) absorption.

3.2. Radioactivity distribution of radioisotopes

Oki et al showed the effect of isotopes on the radioactivity aerodynamic diameter distribution. The radioiotopes of cobalt have very similar radioactivity aerodynamic diameter distributions [5]. Because the impact of radioactivity aerodynamic diameter distribution is determined by chemical compositions, not the type of radioisotope.

Hence, we can use non-radioisotopes for the experiments instead of the radioisotopes to predict the amount and distribution of radioactive aerosol generation.

3.3. Necessity of high-resolution capabilities in the measurement system

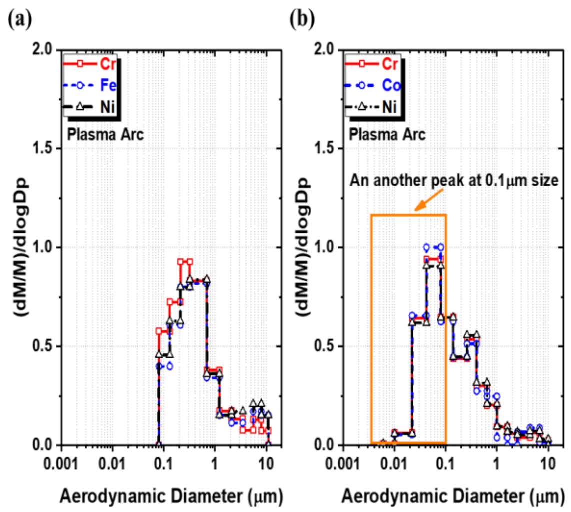

Fig. 4. (a) Mass aerodynamic diameter distribution of chromium, iron, and nickel elements in aerosols from stainless steel sample cut with plasma arc torch. The data points were extracted from Oki et al. [5]. (b) Mass aerodynamic diameter distribution of chromium, cobalt, and nickel elements using ELPI+.

Figure 4 shows that the mass distributions of each element in the aerosols from stainless steel cutting look quite similar. However, the mass aerodynamic diameter distributions from using ELPI+ have another peak at below 0.1 μm size region. As mentioned in the previous section, a typical cascade impactor has a limit to measure particles under 0.1 μm size. As shown above, inadequate selection of measuring equipment may result in the omission of information from small aerosols, which may underestimate the risk of aerosols.

4. Conclusion

It is significant to fully understand the characteristics of aerosol (i.e. aerodynamic diameters, radioactive isotopes, and chemical forms) for evaluating the worker's internal exposure. The aerosol measurement system in KAIST Nuclear Fuel Cycle laboratory could help to confirm the characteristic of aerosol generated from the metal cutting. The data on the physical and chemical properties of aerosols occurring during metal cutting is expected to help establish work procedures for radiation safety of workers in D&D.

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