Evaluation of ^{18}F Radioactive Concentration in Exhaust at Cyclotron Facility at Chosun University

Cheolki Jeong, Daeseok Kim, Han Jang, Gyeongjin Lee*
Radiation Technology Enhancement Center, Chsoun Univ., 309 Pilmun-daero Dong-gu Gwangju 61452, Rep. of Korea
**Corresponding author: kjblee@chosun.ac.kr*

1. Introduction

The recent prevalence of PET examinations in Korea has caused a sharp increase in the number of cyclotrons. Of the 41 cyclotrons operating in Korea, 39 were introduced after the year 2000. The cyclotrons currently operating in Korea, which can yield an average energy of 13–18 MeV, are the same type that is used by large hospitals nationwide to synthesize medical isotopes [1].

Of the many positron-emitting nuclides used in PET imaging, $^{18}F(t_{1/2}=109.8min)$ is the main radioactive isotope generated by cyclotrons[2]. Most cyclotron facilities produce ^{18}F because it has a relatively long half-life and can be easily tagged by organic synthesis methods. Therefore, most ^{18}F produced in Korea is the representative positron-emitting nuclide used in the [^{18}F]FDG synthesis.

The ^{18}F produced by cyclotrons is mostly synthesized into [^{18}F]FDG, and some of it, along with the FDG precursor, is released from the synthesizer as ions without labels. Concerning the radioactive concentration of ^{18}F in exhaust, the Nuclear Safety Act limits the concentration to an emission limit. Accordingly, all cyclotron facilities in South Korea are designed to pass exhaust gases through three stages of filters—a pre-filter, HEPA filter, and Charcoal filter—before it is discharged into the environment. An operating stack monitor is also installed between the three-stage filter unit and the exhaust outlet to monitor the radioactive concentration of ^{18}F in the exhaust.

In this study, we establish and apply a method for evaluating the radioactive concentration of ^{18}F in the exhaust of the cyclotron facility at Chosun University.

2. Methods and Results

2.1 ^{18}F Source

The main emitter of ^{18}F in a cyclotron facility is the [^{18}F]FDG automatic synthesizer. The ^{18}F produced in the cyclotron, mostly in the form of $^{18}F^-$ ions in $H_2{}^{18}O$ water and partially in the form of HF, is transported to the [^{18}F]FDG synthesizer. The ^{18}F collected in the anion-exchange resin undergoes the organic synthesis labeled in the FDG precursor in the automatic synthesizer, and the ^{18}F ions that do not bond with the FDG precursor during the synthesis are emitted to the outside. The ^{18}F released from the [^{18}F]FDG automatic synthesizer is emitted into the environment through the exhaust equipment, after passing through the air-conditioning system of the cyclotron facility. Figure 1 shows the emission of the ^{18}F produced in the cyclotron into the environment via the [^{18}F]FDG equipment.

The unlabeled ^{18}F in the [^{18}F]FDG synthesis is ultimately collected at the exhaust filter in the cyclotron facility, and the remaining uncollected ^{18}F is emitted into the environment.

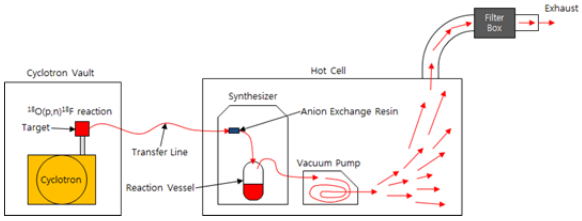

Fig. 1. ^{18}F production and discharge path

2.2 ^{18}F Sampler

As shown in Figure 2, the exhaust system was used to evaluate the radioactive concentration of ^{18}F in the exhaust of the cyclotron facility at Chosun University, and the concentration of exhaust specimens was estimated.

NAC-100 Impregnated Charcoal Filter of NAC CO. LTD was used as the sampling charcoal filter. An NDAS-0200 Air Sampler from NEOSISKOREA Co., LTD was used as the air sampler, and a gamma-ray analysis of the collected samples was performed using a GC1518 HPGe detector from Canberra Co. and the software Genie 2000.

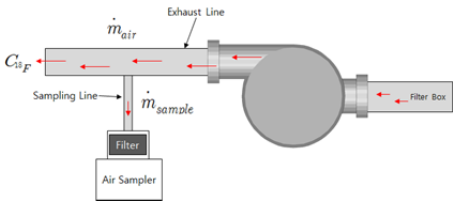

Fig. 2. ^{18}F exhaust and sampler

2.3 Discharge Criterion

As a nuclear power usage facility, a cyclotron facility must control the amount of gaseous radioactive waste that it emits in accordance with the "Nuclear Safety and Security Commission Article No. 2014-34, Criteria on

Radiation Protection." This regulation limits the amount of ^{18}F in exhaust to 2,000 Bq/m^3. Therefore, a cyclotron facility that uses mainly ^{18}F for [^{18}F]FDG synthesis should measure and regulate the radioactive concentration of ^{18}F in the exhaust in compliance with this regulation.

2.4 Radioactive concentration of ^{18}F in exhaust

The air sampler shown in Figure 2 was used to collect and measure samples. The sampling time for one sample was 540 seconds(T_1), the measurement preparation time was 100 seconds(T_2), and the duration of the measurement using the HPGe semiconductor detector was 540 seconds(T_3). Samples were collected and measured every 10 min. Figure 3 shows the time ranges for the radioactive-decay correction of one sample.

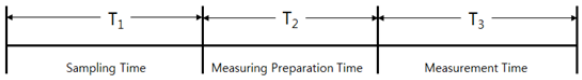

Fig. 3. Sampling and measurement time

The radiation of one sample collected at the air sampler, prepared for measurement, and measured—for durations of T_1, T_2, and T_3 time—is as follows:

$$A_{sample} = C_{18_F} \times (\dot{m}_{sample} \times T_1) \times f_1 \times f_2 \times f_3 \quad \text{(Bq), -------- (1)}$$

where

C_{18_F} : radioactive concentration of ^{18}F in exhaust (Bq/m^3)
$\dot{m}_{sample} \times T_1$: amount of collected sample (m^3)
f_1 : decay correction factor for sampling time, $(\frac{1-e^{-\lambda T_1}}{\lambda T_1})$
f_2 : decay correction factor for measuring preparation time, $(e^{-\lambda T_2})$
f_3 : decay correction factor for measurement time, $(\frac{1-e^{-\lambda T_3}}{\lambda T_3})$

Rearranging Eq. 1 gives Eq. 2, which indicates the radioactive concentration of ^{18}F in the exhaust.

$$C_{18_F} = \frac{A_{sample}}{(\dot{m}_{sample} \times T_1) \times f_1 \times f_2 \times f_3} \quad \text{(Bq/m}^3\text{) ------- (2)}$$

2.5 Evaluation of radioactive concentration of ^{18}F in exhaust

Figure 4 shows the radioactive concentration of ^{18}F in the exhaust, which was evaluated using Eq. 2 for different [^{18}F]FDG synthesis yields.

The results show that the ^{18}F concentration increased for 10 min after the start of [^{18}F]FDG synthesis and was maximized ~10 min before and after the completion of the [^{18}F]FDG synthesis. Furthermore, the ^{18}F concentration at a high [^{18}F]FDG synthesis yield was lower than that at a low synthesis yield, indicating that the ^{18}F emitted into the atmosphere was due to ^{18}F that was not synthesized into [^{18}F]FDG.

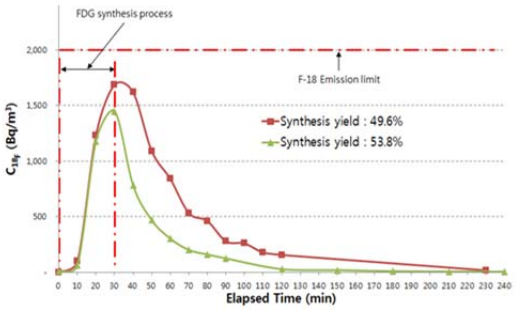

Fig. 4. Change in the radioactive concentration of ^{18}F in exhaust over time

The ^{18}F emission concentration of the cyclotron facility at Chosun University was maintained below the ^{18}F emission limit of 2,000 Bq/m^3.

3. Conclusions

We established a practical method for evaluating the radioactive concentration of ^{18}F in exhaust by sampling the air released from the cyclotron facility at Chosun University. We evaluated the ^{18}F concentration at the point of maximum emission, as well as its adherence to the emission limit.

The radioactive concentration of ^{18}F in the exhaust was analyzed using the ^{18}F emission evaluation model presented in this paper. The analysis confirmed that the cyclotron facility at Chosun University controlled the emission concentration to 80% of the emission limit or less. However, if the ^{18}F production increases at this facility, the ^{18}F concentration may temporarily exceed the limit; in this case, additional studies on the reduction of the ^{18}F emission are required.

Acknowledgement

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REFERENCES

[1] Korea Institute of Nuclear Safety, Analytical evaluation of domestic operational reality for cyclotron and internal and external facility dismantling standard, KINS/HR-1269, 2013.
[2] Chi DY. The development of radiopharmaceuticals for human body imaging. J Korean Ind Eng Chem 2003;14:253-62.