Technical Paper

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

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Abstract - The recent prevalence of PET examinations in Korea has led to an increase in the number of cyclotrons. The medical isotope ^{18}F produced in most cyclotron facilities currently operating in Korea is emitted into the environment during the production of [^{18}F]FDG, a cancer-diagnosis reagent. The amount of [^{18}F]FDG synthesized determines the radioactive concentration of ^{18}F in the exhaust. At some facilities, this amount temporarily exceeds the emission limit. In this study, we evaluated the ^{18}F radioactivity concentration in the exhaust from the cyclotron facility at Chosun University. The ^{18}F radioactivity concentration was measured using an air sampler and a HPGe semiconductor detector. The measurements showed that the radioactive concentration of ^{18}F in the exhaust at the cyclotron facility at Chosun University was the highest during [^{18}F]FDG synthesis but remained under the legal limit of 2,000 Bq m^{-3}.

Key words : PET, Cyclotron facility, [^{18}F]FDG, Synthesizer, ^{18}F radioactivity concentration

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 (KINS/RR-1116. 2014).

Of the many positron-emitting nuclides used in PET imaging, ^{18}F ($t_{1/2}$ = 109.8 min) is the main radioactive isotope generated by cyclotrons (Chi 2003). 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 radioactivity 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 radioactivity concentration of ^{18}F in the exhaust.

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

MATERIAL AND METHODS

1. ^{18}F Source

The main emitter of ^{18}F in a cyclotron facility is the

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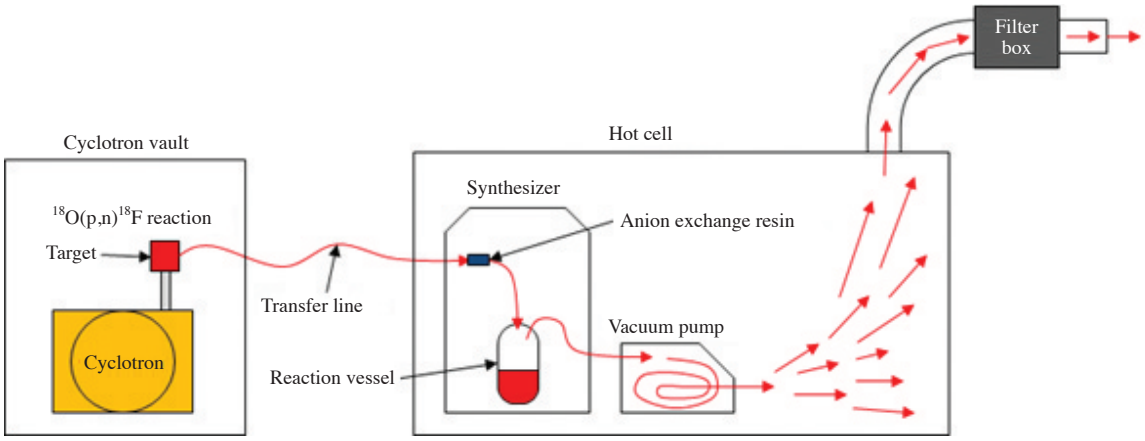

Fig. 1. ^{18}F production and discharge path.

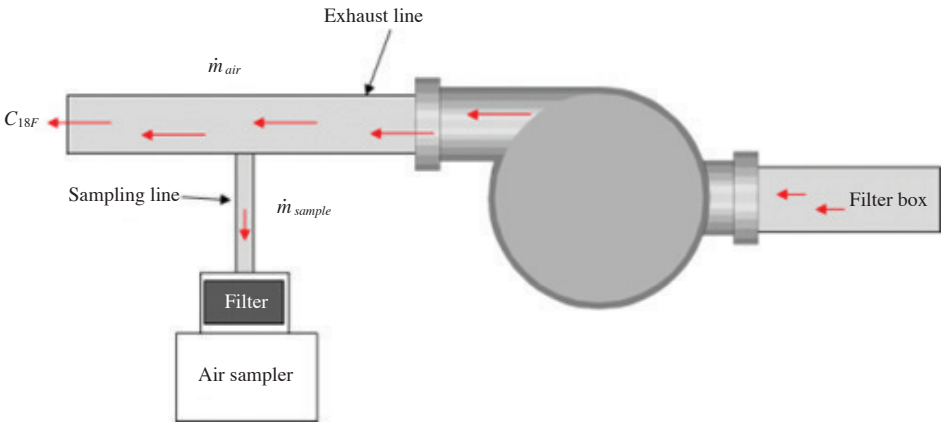

Fig. 2. ^{18}F exhaust and sampler.

[^{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. Fig. 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.

2. ^{18}F sampler

As shown in Fig. 2, the exhaust system was used to evaluate the radioactivity 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.

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

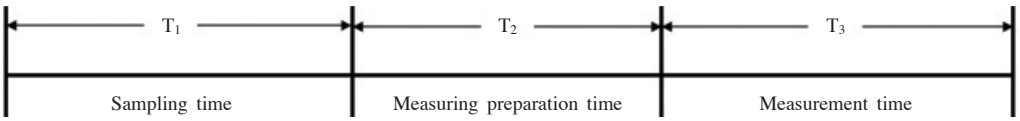

Fig. 3. Sampling and measurement time.

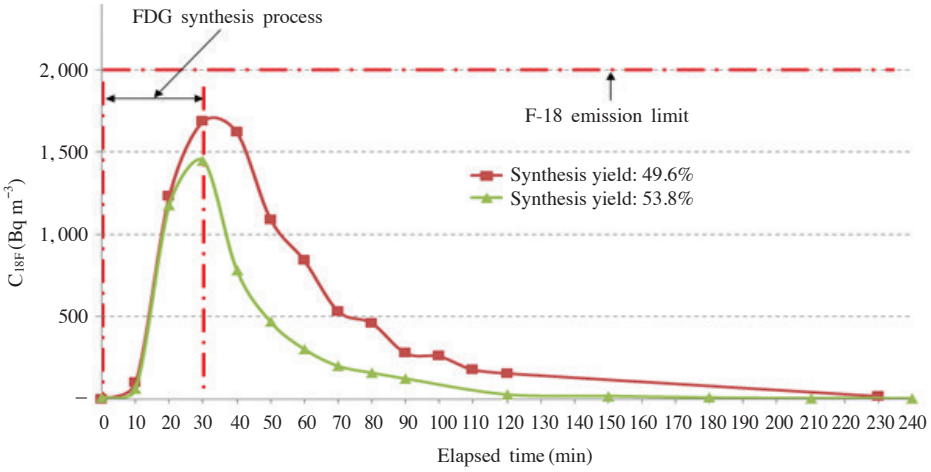

Fig. 4. Change in the radioactivity concentration of ^{18}F in exhaust over time.

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 radioactivity concentration of ^{18}F in the exhaust in compliance with this regulation.

RESULTS

1. Radioactivity concentration of ^{18}F in exhaust

The air sampler shown in Fig. 2 was used to collect and measure samples. The sampling time for one sample was 540 seconds (T1), the measurement preparation time was 100 seconds (T2), and the duration of the measurement using the HPGe semiconductor detector was 540 seconds (T3). Samples were collected and measured every 10 minutes. Fig. 3 shows the time ranges for the radioactive-decay correction of one sample.

The radiation of one sample collected at the air sampler, prepared for measurement, and measured–for durations of T1, T2, and T3 time–is as follows:

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

where

C_{18_F}: radioactivity 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, $\left(\frac{1-e^{-\lambda T_1}}{\lambda T_1}\right)$

f_2: decay correction factor for measuring preparation time, $(e^{-\lambda T_2})$

f_3: decay correction factor for measurement time, $\left(\frac{1-e^{-\lambda T_3}}{\lambda T_3}\right)$

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

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

2. Evaluation of radioactivity concentration of ^{18}F in exhaust

Fig. 4 shows the radioactivity concentration of ^{18}F in the exhaust, which was evaluated using Eq. 2 for different [^{18}F]FDG synthesis yields (Tables 1 and 2).

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

Table 1. Radioactivity concentration of ^{18}F in exhaust over time (Synthesis yield: 53.8%)

Elapsed time (min)	Net counts	A (Bq)	Sampling time (sec)	$\dot{m}_{Sample}$	f_1	f_2	f_3	Concentration Bq m^{-3}
0	201	8	540	0.0024	0.972	0.987	0.972	10
10	1187	48	540	0.0024	0.972	0.983	0.972	61
20	23093	934	540	0.0024	0.972	0.985	0.972	1179
30	28203	1140	540	0.0024	0.972	0.982	0.972	1450
40	15217	615	540	0.0024	0.972	0.982	0.972	781
50	9127	369	540	0.0024	0.972	0.982	0.972	468
60	5886	238	540	0.0024	0.972	0.980	0.972	302
70	3899	158	540	0.0024	0.972	0.982	0.972	200
80	3108	126	540	0.0024	0.972	0.981	0.972	159
90	2385	96	540	0.0024	0.972	0.972	0.972	124
120	541	22	540	0.0024	0.972	0.983	0.972	28
150	364	15	540	0.0024	0.972	0.990	0.972	18
180	175	7	540	0.0024	0.972	0.988	0.972	9
210	122	5	540	0.0024	0.972	0.988	0.972	6
240	99	4	540	0.0024	0.972	0.983	0.972	5

Table 2. Radioactivity concentration of ^{18}F in exhaust over time (Synthesis yield: 49.6%)

Elapsed time (min)	Net counts	A (Bq)	Sampling time (sec)	$\dot{m}_{Sample}$	f_1	f_2	f_3	Concentration Bq m^{-3}
5	0	0	240	0.0023	0.987	0.986	0.987	0
10	299	27	240	0.0023	0.987	0.987	0.987	78
15	988	90	240	0.0023	0.987	0.987	0.987	258
20	2856	260	240	0.0023	0.987	0.987	0.987	750
25	4799	437	240	0.0023	0.987	0.987	0.987	1260
30	4702	428	240	0.0022	0.987	0.987	0.987	1238
35	3787	345	240	0.0023	0.987	0.987	0.987	994
40	3133	285	240	0.0023	0.987	0.987	0.987	823
45	2530	230	240	0.0023	0.987	0.987	0.987	665
50	1893	172	240	0.0022	0.987	0.986	0.987	499
55	1529	139	240	0.0022	0.987	0.986	0.987	403
60	1450	132	240	0.0022	0.987	0.915	0.987	412
90	778	71	240	0.0023	0.987	0.988	0.987	204
120	488	44	240	0.0022	0.987	0.988	0.987	128
150	205	19	240	0.0023	0.987	0.987	0.987	54
180	155	14	240	0.0023	0.987	0.989	0.987	41

[^{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.

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}.

DISCUSSION

We established a practical method for evaluating the radioactivity 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.

CONCLUSION

The radioactivity 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 con-

centration may temporarily exceed the limit; in this case, additional studies on the reduction of the ^{18}F emission are required.

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