Preliminary Estimation of Ar Gas Activation at Electron Beam Dump of PAL-XFEL

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1. Introduction

The air activation is the one of the concerned issues in large accelerator facilities. Among the radionuclides generated in the air inside the accelerator tunnel, H-3 and Ar-41 are important radionuclides because their half-lives are longer than others such as O-15, C-11, N-13, etc. However, the measurement results are insufficient because of the difficulty of the measuring of activated gas.

In this study, Ar-41 was measured inside the main beam dump bunker of PAL-XFEL. This area is suitable for this experiment since high-energy electrons are always lost in the main beam dump during the normal operation. Ar-41 is produced by the thermal neutron capture reaction of Ar in air. Ar gas sealed in prepared sampling bags is irradiated in a stray radiation field generated by the electron loss, and the radioactivity concentration of Ar-41 in sampling bag was measured through the gamma-ray spectroscopy. The Ar-41 concentration was also estimated using the thermal neutron flux measured by Au foil installed in front of the sampling bag and compared with the measured value

2. Methods and Results

2.1 Estimation of Ar-41 radioactivity concentration

In the case of Ar-41, it is generated from the thermal neutron capture reaction, and the concentration in saturated air was calculated using Swanson's fast neutron generation rate per unit power and Patterson's equation for estimating thermal neutron flux. The concentration of Ar-41 in saturated air is as follows [1, 2];

$$C_{sat,\,Ar-41} = \Phi_{th} \times \sigma_{th} \times N_{avo} \times \rho \times f/A \ [\mathrm{Bq/m^3}]$$

Φ_{th} : Thermal neutron flux
σ_{th} : Thermal neutron cross-section of Ar-40(n,γ)Ar-41 (= 0.53 b)
N_{avo} : Avogadro number (= 6.02 $\times 10^{23}$)
ρ : Density of air (= 1.205 $\times$ 10^3 g/m^3)
f : Weight fraction of ^{40}Ar in air (= 0.013)
A : Mass of ^{40}Ar (= 40)

The concentration of Ar-41 can be calculated based on the thermal neutron flux. In order to check the thermal neutron flux, Au foil is used [3]. The two Au foils are prepared. First foil is for bare irradiation condition and second foil is Cd covered to absorb neutron. The thermal neutron flux can be derived from the measurement of two irradiated sample.

Fig. 1. The Cd covered Au foil sample (left) and bare Au foil sample (right)

The irradiation profile of electron beam is shown in Fig. 2. The irradiation time was 73 hours 52 min and the averaged beam charge was 184 pC. However, the electron beam energy was changed 8 GeV to 9.2 GeV. Since this experiment was performed at the user beamtime period, the electron beam energy could be changed according to needs of the beamline users.

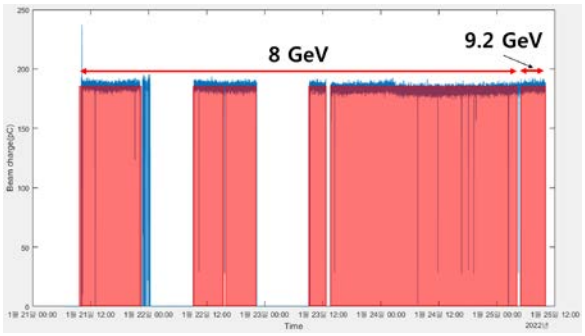

Fig. 2. PAL-XFEL operation and irradiation profile

From the gamma-ray spectroscopy results of Au foils, thermal neutron flux at the nearest sampling bags from the target was estimated as (8.2 ± 2.2) × 10^5 n/cm2/s and the Cd ratio was 1.83 ± 0.02. Therefore, the radioactivity concentration of Ar-41 can be estimated as (1.2 ± 0.3) × 10^4 Bq/L.

2.2 Measurement of Ar-41 radioactivity concentration

In order to measure the radioactivity concentration of Ar-41, Ar-40 gas was collected and it was placed around the electron beam dump to irradiate. The 99.9999 % of Ar-40 is collected at 1.3 L of polyvinylfluoride sampling bag and the sampling bags filled with Ar-40 gas were installed near the electron beam dump like Fig. 3.

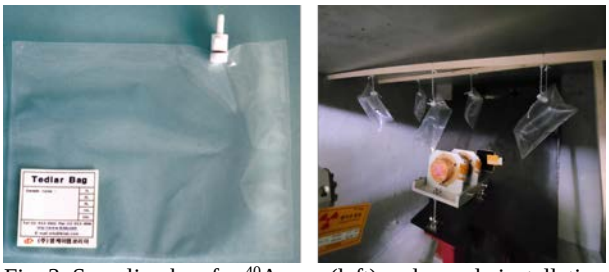

Fig. 3. Sampling bag for ^{40}Ar gas (left) and sample installation around the electron beam dump (right)

After irradiation for a certain period of time, the sampling bag was taken and gamma spectroscopic analysis was performed. To measure the gamma-ray of 1,294 keV from Ar-41 of sampling bag and 412 keV from Au-197, the HPGe detector (relative efficiency: 20%) was used. For the sampling bag of Ar-41, the In-Situ Object Calibration Software (ISOCS) by CANBERRA, Inc. [4], was used to determine the full energy peak efficiency as shown in Fig 4. For the Au foil, several point sources were used with same distance of 10 cm from detector surface. The geometric correction factor between the point source and Au foil was almost 1. The procedure for gamma spectroscopic analysis is described at Table 1. The net peak area is determined by subtracting after background fitting with the peak left and right 4 channels.

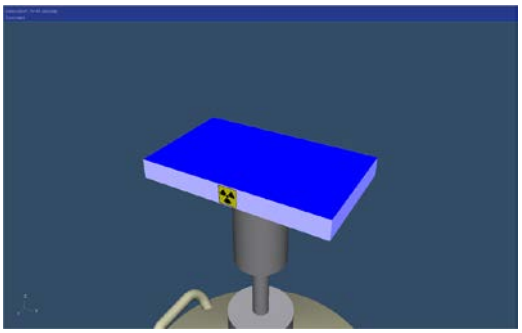

Fig. 4. The geometrical model of measurement for Ar sampling bag (blue cuboid structure)

Table 1. Procedure for gamma spectroscopic analysis

Channel-Energy calibration
Sample position determination
Absolute efficiency correction
Gamma-ray spectrum acquisition
Peak locate & area analysis
Nuclide identification
Detection limit calculation
Reporting

In the sampling bag measurement, the acquisition of the gamma-ray spectrum was started quickly because of the short half-life of Ar-41 (109.34 min). The first acquisition was started 16 min after the end of irradiation. An averaged value of the radioactivity concentration was obtained from three measurements before the decay-out, and it was (1.45 ± 0.03) × 104 Bq/L for the nearest sampling bag. As shown in Fig 5, Ar-41 peak at 1294 keV could be confirmed well.

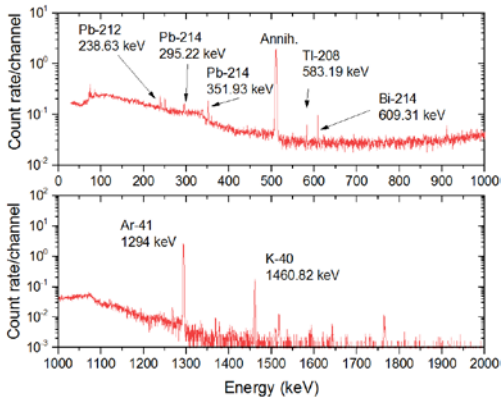

Fig. 5. The measured spectrum of ^{41}Ar activated sample

Since the half-life of ^{41}Ar is very short as 109.34 min, the irradiated sample was measured twice for 1,800 seconds. The time difference from the measurement after irradiation was corrected, and the measured ^{41}Ar radioactivity concentrations were (1.40 ± 0.02) × 10^4 and (1.46 ± 0.02) × 10^4 Bq/L, respectively.

3. Conclusions

The Ar-41 gas production in the beam dump bunker of PAL-XFEL was estimated. The radioactivity concentration of Ar-41 was measured directly and estimated based on the thermal neutron flux by Au foil. Both results were consistent, and through this, the adequacy of Ar-41 gas measurement method was verified. It is planned to analyze the difference in the amount of Ar-41 generation according to the electron beam energy through an additional experiment that limits the specific electron beam energy, and to perform comparative analysis through the activation analysis techniques such as Monte Carlo code.

REFERENCES

[1] Swanson, William P. "Radiological safety aspects of the operation of electron linear accelerators.", 1979.
[2] Patterson, H. Wade, ed. Accelerator health physics. Elsevier, 2012.
[3] N.S. Jung, Y.U. Kye, H. H. Kim, H. S. Lee, “Induced radioactivity of metal samples in the radiation field by 9.6 GeV electrons at PAL-XFEL”, ARIA 19, Sep.23-25, 2019, Daejeon, Korea.
[4] Canberra, Model S573 ISOCS Calibration Software USER’s Manual, 2002.