Design of Radioactive Krypton Detection System using PIPS Detector

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1. Introduction

One of the anthropogenic source of the radioactive noble gas ^{85}Kr (beta emitter, E_{max} : 687 keV, half-life : 10.76 years) is nuclear fuel reprocessing.[1] Because radioactive krypton is one of the nuclear by-products released during nuclear test or reprocessing, and if we detect the radionuclide at the atmosphere, it will be a strong evidence of nuclear test or reprocessing. Currently, various equipment to detect radioactive krypton is researched and operated at several countries under the CTBTO. In Korea, the gas proportional counter made by a Budesamt für Strahlenschutz - Institute of Atmospheric Radioactivity (BfS-IAR) was operated to monitor the unreported nuclear activities of neighboring countries.[2, 3] Because the system was needed continuous P-10 gas injection, it is difficult to operate and maintain the system developed in remote areas. Therefore, it is necessary to develop a compact and modular radioactive krypton monitoring system to maintain easily.

2. Methods and Results

Among the detectors that can be applied to automate krypton detection system, the semiconductor detector has the advantage that the memory effect of the sample does not occur. In this study, we developed the design of radioactive krypton detection system using PIPS detector as semiconductor detector.

2.1 PIPS Detector

There are several types of semiconductor detectors depending on the arrangement and type of diodes. It created the electron hole-pair by radiation. In general, semiconductor type detectors have a disadvantage in that they are used at low temperature using liquid nitrogen to minimize the leakage current. However, silicon drift detector as semiconductor detectors that can be used at room temperature have been developed, and it has low work function (3eV) and high energy resolution. Among the semiconductor detectors, some studies related to beta nuclide analysis using PIPS (Passivated Implanted Planar Silicon) detectors are being conducted.[4] PIPS has a window thickness of about 50nm or less, and such a thin thickness is related to the transmission of low-energy beta, which can result in improved resolution and low energy threshold. In previous studies [5], for the measurement of ^{85}Kr with a maximum energy of 687 keV, a PIPS detector with a large area in contact with the sample has a great advantage in improving detection efficiency. In the view of a thickness, the overall efficiency is similar for a thickness of 300 ㎛ or more. However, a thickness of 500 ㎛ or more is suitable to increase the reaction probability in the high energy region. In the case of partially depleted PIPS, there are products with a maximum thickness of 1000 ㎛, but it has a limitation in detection efficiency because the largest area of the product is 300 mm^2. Therefore, in this study, the system design was conducted using PIPS with a wide area 450 mm^2 or more among products with a thickness of 500 ㎛.

2.2 Design of the Radioactive Krypton Detection System

In terms of efficiency, it is reasonable to construct a system using a 1200 mm^2 PIPS detector with 500 ㎛ thickness. However, because the larger the size of the silicon detector, the greater the noise, the system were designed to evaluate the actual noise and efficiency using both 450 mm^2 and 1200 mm^2 with 500 ㎛ thickness. As shown in Figure 1, it is designed to increase the detection efficiency by configuring krypton gas to pass between two PIPS and to receive and process signals from each PIPS. The system includes a gas collection and detection unit, and electronics for signal processing.

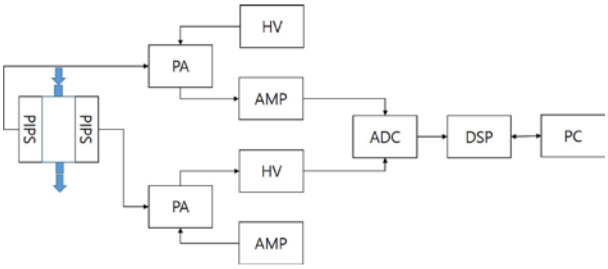

Fig. 1. Design of the radioactive krypton detection system using two PIPS detector

2.3 Monte Carlo Simulation

Before the manufacture of the system, we evaluated the efficiency of the system using MCNP. The schematic diagram of the system using two PIPS, the structure using MCNP and the distribution of ^{85}Kr source are shown in Figure 2. The volume between the two detectors was designed to be 30 cm^3 at a pressure of 1 atmosphere, and the gap between detectors can be reduced by gradually increasing the pressure. We predicted that up to 3 atmosphere is possible, and Table 1 shown the interval between two PIPS according to the pressure increase.

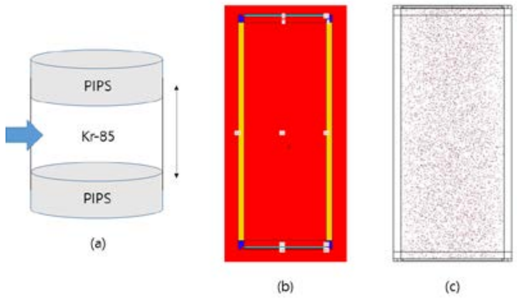

Fig. 2. (a)Schematic diagram of the system using two PIPS, (b) the structure using MCNP and (c) the distribution of ^{85}Kr source

Table I: Distance between two PIPS

Pressure (atm)	PIPS (450 mm^2)	PIPS (1200 mm^2)
1	6.67 cm	2.5 cm
2	4.44 cm	1.67 cm
3	2.22 cm	0.83 cm

When the pressure is increased, because the distance between the source and the PIPS is closer, the reaction probability is higher. The reaction probability can be decreased by the density increase of gas, however, the decrease effect is much smaller than the increase effect by distance decrease. For example, in the case of 1200 mm^2 PIPS, the efficiency increases by about 10 % when the pressure is increased by 1 atmosphere. At this time, the efficiency decreases according to the change of the gas density by about 1 %. Accordingly, the evaluation of reaction probability according to the pressure for two types of PIPS are shown in Figure 3 and 4.

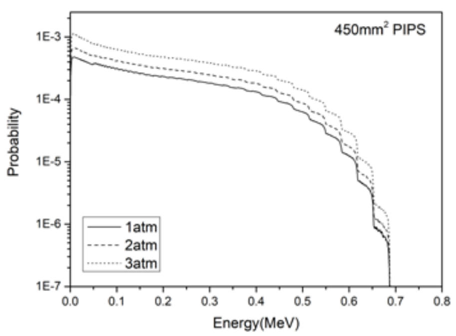

Fig. 3. Reaction probabilities of PIPS with an area of 450 mm^2 according to the atmosphere

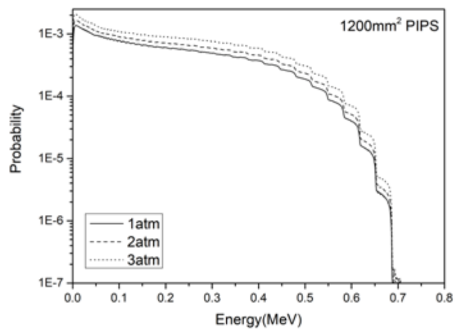

Fig. 4. Reaction probabilities of PIPS with an area of 1200 mm^2 according to the atmosphere

Using PIPS with an area of 450 mm^2, the reaction probabilities are 14.8, 20.1 and 31.3 % when the pressure is 1, 2 and 3 atmospheres, respectively. Using PIPS with an area of 1200 mm^2, the reaction probabilities are 39.4, 47.1 and 58.9 %.

3. Conclusions

In this study, we designed the radioactive krypton monitoring system using PIPS detector. We evaluated the reaction probabilities for PIPS using MCNP simulation, and from these results, it is appropriate to compose the system of two 1200 mm^2 PIPS and to operate at 3 atmosphere. However, as mentioned above, because the noise is high when the area of PIPS is large, so if the ROI excluding the low energy regions considering noise is set, the actual measurement efficiency will be lower than the simulation result. In the future, we will make up the system and evaluate the real noise and efficiency.

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