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Development of a Portable Direction Finding Device of Radioactive Source using Quadrupole NaI(Tl) Detectors

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1. Introduction

Korea Institute of Nuclear Safety (KINS) studied the direction finding algorithm of radioactive materials to detect sources quickly and efficiently in the situation of radiological accidents or terrorism [1]. And a Portable Radioactivity Direction Finding (PDF) device using this algorithm has been developed. PDF device uses the principle that the count-rate of each detector is different between the four NaI(Tl) detectors (arranged like as quadrupole) due to the shielding effect depending on the incident angle of radiation [2]. In this study, the criteria of direction finding with the newly developed PDF device were derived and its performance was verified.

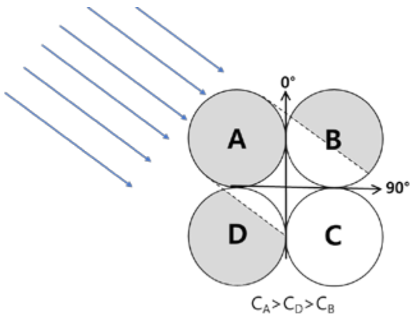

Fig. 1. Concept of PDF principle (C_i: count-rate of detector i).

2. Methods and Results

2.1 Compose of Device and Experiment

PDF device is composed of 4EA Φ2``×3`` NaI(Tl) detectors, and a lead shield (5mm) is installed between the detectors in a cross shape. The lead shield can prevent simultaneous counting. So, the direction finding sensitivity of the device can be improved. The total weight of PDF is about 12 kg, the size is 20cm×32cm×45cm, and it can be installed and operated on a dedicated tripod.

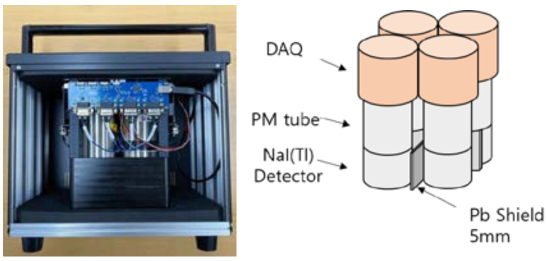

Fig. 2. Structure of PDF device.

Cs-137 (2.58 MBq) and Co-60 (4.44 MBq) sources were used in the measurement experiment for deriving direction finding criteria, and measurements were made at 0~300cm (50cm intervals), and from 270° to 360° for (11.25° intervals). The measurement time was 1 minute at each point.

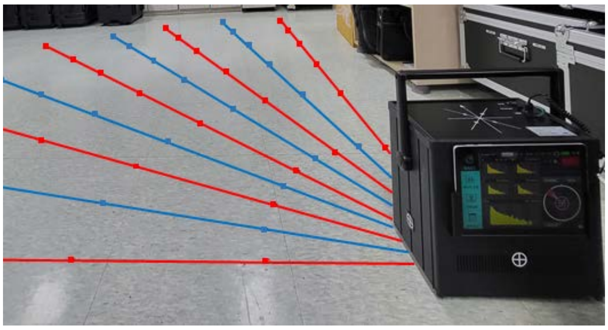

Fig. 3. Experimental setting.

The count-rate of each detector was obtained by summing the total spectral counts in the entire energy region (0~3MeV). For efficiency correction between detectors, the count-rates were measured in the directions of 0° (C_A=C_B), 90° (C_B=C_C), 180° (C_C=C_D), 270° (C_D=C_A) where the count-rates of two detectors are theoretically identical. Each correction coefficient to detector A was derived through the ratio of the measured count-rates and used in the algorithm.

2.2 Trend with Angle

Fig. 4 shows the measured results to verify the change in the count-rate of each detector according to the radiation incident angle.

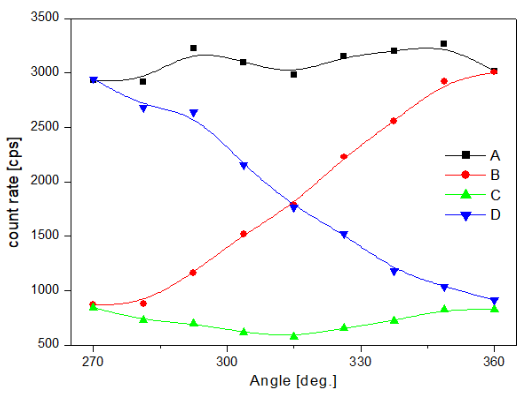

Fig. 4. Change in count-rate of each detector according to incident angle (Cs-137 2.58MBq, 50cm).

Since the range of measured angle is 270~360°, the count-rate of detector A is the highest. Before 315°, the count-rate of detector D appears second, and after that, the count-rate of detector B becomes second. This trend from 270 to 360° will be repeated by 90° intervals for all angles from 0 to 360°. In consideration of this, in order to obtain the direction finding criteria for all directions, the detectors were not classified into A~D, but were classified according to the count-rate ranking.

Fig. 5 and 6 show the relative trend of the count-rate (C_n: n-th rank's count-rate) ratio between each detector according to the direction angle. In Fig. 5, the C_2/C_1 (count-rate ratio of the second order detector B or D to the first order detector A) is close to 1 on the orthogonal direction (270°, 360°). This is because the count-rates of the first and second order detectors are almost the same. At the 315° position, the count-rate ratio appears the lowest. In Fig. 6, the C_3/C_2 is close to 1 on the diagonal direction (315°), because the count-rates of detectors B and D are almost the same. And it shows the lowest value at 270° and 360°. Although there is a difference in the count-rate ratio according to the distance, it is confirmed that the tendency is almost similar.

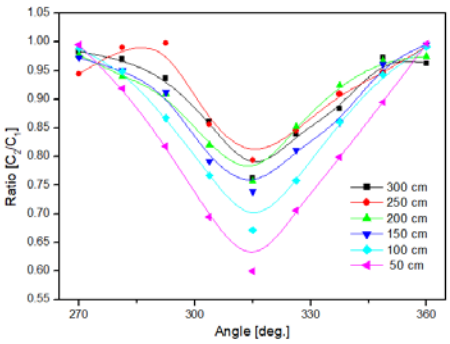

Fig. 5. Change in count-rate ratios according to angle (Cs-137, C_2/C_1).

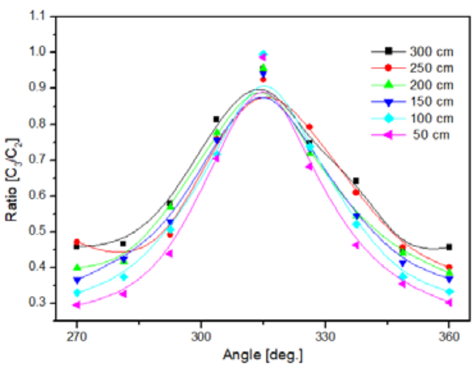

Fig. 6. Change in count-rate ratios according to angle (Cs-137, C_3/C_2).

2.3 Derivation of R_s, R_t

As described above, the C_2/C_1 will be almost 1 on the orthogonal direction (0°, 90°, 180°, 270°), and the C_3/C_2 will be almost 1 on the diagonal direction (45°, 135°, 225°, 315°). However, since measurement errors and others are reflected, it is difficult for the ratio to be exact 1 even if it is incident on the accurate angle. Therefore, a criterion for determining whether the count-rate ratio is close to 1 is required.

In order to establish these criteria, an angle of ±11.25° was set as a boundary condition with orthogonal and diagonal directions. This is an angle corresponding to the error range by dividing the entire 360° into 16 areas. C_2/C_1 at the boundary angle is defined as R_s (orthogonal direction), and C_3/C_2 is defined as R_t (diagonal direction). When $R_s < C_2/C_1 \leq 1$, it can be determined as an orthogonal angle direction, and when $R_t < C_3/C_2 \leq 1$, it can be determined as a diagonal angle direction. In the region of 270 to 360°, the values at 281.25° and 348.75° are R_s, and the values at 303.75° and 326.25° become R_t.

Fig.7 shows the Rs and Rt values measured by distance for Co-60 and Cs-137. It can be confirmed that R_s and R_t increase and become saturated with distance. This has been confirmed through computational simulation in the previous study [1]. This is because as the distance increases, the effect of the distance difference between the detector decreases unlikely as shown in Fig. 8 (in short-distance), and almost parallel incidence occurs. As shown in Fig. 7, the R_s and R_t values at the short and long are different. The short-distance ratio determined with the average value of 0~3m values can be used for a checking purpose. And, the long-distance ratio obtained through exponential function fitting can be used for actual field detection. The derived values are shown in the Table. I.

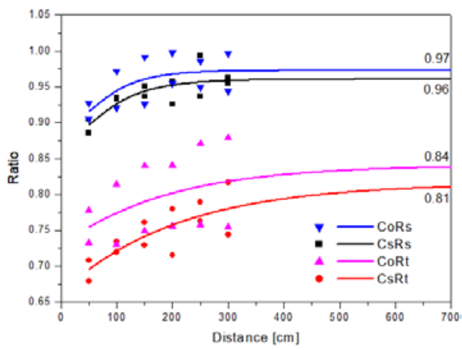

Fig. 7. Derivation of R_s, R_t.

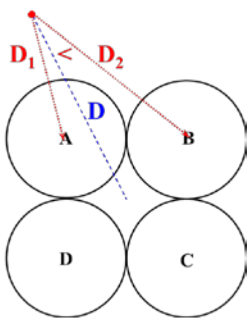

Fig. 8. Causes of saturation of count-rate ratio (D_n: distance between source and center of n-th order detector).

Table I: R_s, R_t for short and long distances.

Nuclide	Distance		R_s	R_t
Cs-137	Short		0.94	0.75
	Long		0.96	0.81
Co-60	Short		0.96	0.79
	Long	This	0.97	0.84
		Prev.[1]	0.95	0.90

2.4 Verification of direction finding performance

The direction finding performance of the device was verified using the derived R_s and R_t values. In the long-distance performance check, direction finding was conducted at a distance of 6~9m using 6EA Co-60 sources (total 26.6MBq), and the results are shown in the Fig. 9. It is confirmed that the accuracy decreases as the distance increases. This is due to the effect of the statistical error from low counts. If the count value of the detector is approximately 5,000 counts or less, the accuracy will be worse. However, it did not deviate out of 22.5° even when the direction angle was incorrectly detected. The reason for the low detection accuracy in specific angular regions (near 270°) is presumed that the correction coefficient of detector D was measured lower due to the experimental environment and measurement error.

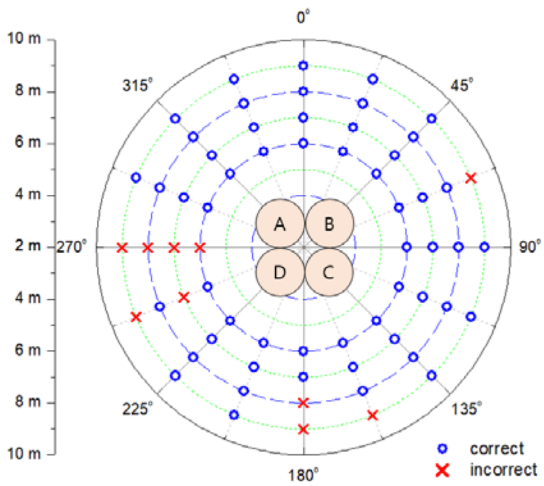

Fig. 9. Result of verification (Co-60 26.6MBq).

3. Conclusions

The PDF device was developed by applying the direction finding algorithm studied through previous research. And the direction finding criteria were experimentally derived and its performance was verified. As a result of verification at a long distance, it was confirmed to be relatively correct. So, it is expected that this device can be used in the actual field.

Also, as suggested in the previous study, a lead shield was installed between the four detectors. As a result of comparing the reinforcement effect of the shield as shown in Fig. 10, it was confirmed that the count-rate ratios changed significantly compared to the previous study. This seems to have improved the direction finding sensitivity of the device.

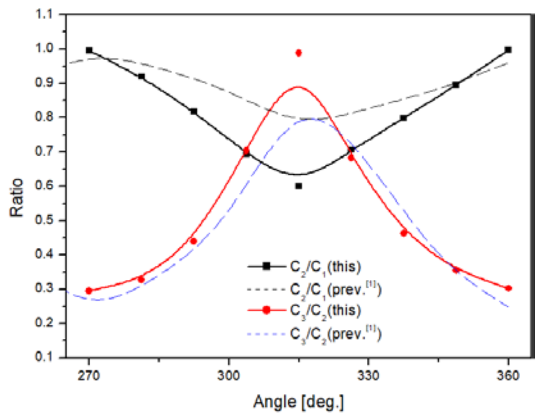

Fig. 10. Comparison of count-rate ratio (Cs-137 with/without shield).

An operating program was also developed as shown in Fig. 11 by applying the derived R_s and R_t. The measured spectra of each detector, summing spectrum and the source direction can be displayed.

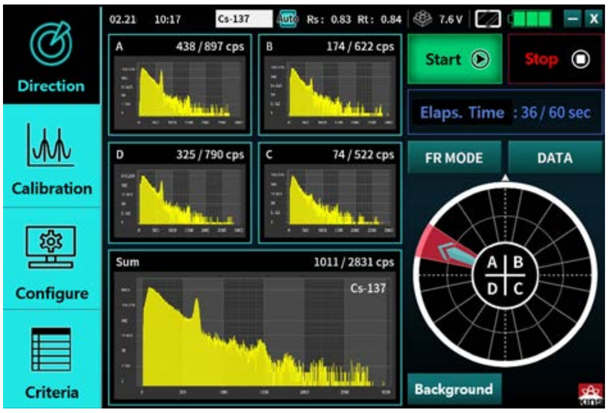

Fig. 11. The operating program of PDF.

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