Study on improvement of scan survey system performance using collimator

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1. Introduction

Radiological characterization of the site is required in decommissioning the nuclear power plant. In MARSSIM(Multi-Agency Radiation Survey and Site Investigation Manual), after HSA(Historical Site Assessment) and survey design stage the scan survey is performed to assess the distribution of radioactivity contamination[1]. The scan survey is carried out by continuously moving the detector and measures the count rate. Based on count rate data, determined that contamination exists at that location if a count rate above the criterion is distinct to the background count rate.

The value used as a reference is the Minimum Detectable Count Rate (MDCR), which means the minimum value in which the count rate by the source can be distinguished to background count rate[2]. Based on the MDCR, there is a possibility that the source size may be overestimated by gamma-rays emitted from the hotspot.

This study conduct to evaluate the degree of variation in scan survey performance and reduction of overvaluation when the collimator is applied. For this, the area source was made by the $_{137}$Cs and $_{60}$Co liquid source with soil. The instrument used a 3inch Na(Tl) detector and a suitable collimator. Also, based on NUREG-1507 report, the scan MDC was evaluated based on the presence of collimators. The scan survey experiment was conducted through uniform motion equipment to compare the size of the actual source and the estimated source. Through this, the effect of collimator during the scan survey is quantitatively evaluated.

2. Methods and Materials

2.1 MDCR and Scan MDC calculation

The MDCR means the minimum count rate at which a signal by a source can be distinguished from a background count rate. Assuming both the distribution of the background count rate and the source count rate follows a Poisson distribution, the standard deviation of the two distributions can be assumed to be the square root of the mean. Thus, depending on the index of sensitivities that rely on the decision error, MDCR is calculated as follows:

$$\mathrm{MDCR} = \mathrm{d}' \times \sqrt{b_i} \times (60/i)$$
$$\mathrm{d}' = Index\ of\ sensitivity,$$
$$b_i = Background\ count\ rate\ (cpm)$$

In this study, the index of sensitivity has been applied as 1.38 by using the 60% false positive proportion and the 95% true positive proportion(Table.1).

Table 1 Index of sensitivity (From NUREG-1507 Report)

False positive Proportion	True positive proportion							
	0.60	**0.65**	**0.70**	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**
0.05	1.90	2.02	2.16	2.32	2.48	2.68	2.92	3.28
0.10	1.54	1.66	1.80	1.96	2.12	2.32	2.56	2.92
0.15	1.30	1.42	1.56	1.72	1.88	2.08	2.32	2.68
0.20	1.10	1.22	1.36	1.52	1.68	1.88	2.12	2.48
0.25	0.93	1.06	1.20	1.35	1.52	1.72	1.96	2.32
0.30	0.78	0.91	1.05	1.20	1.36	1.56	1.80	2.16
0.35	0.64	0.77	0.91	1.06	1.22	1.42	1.66	2.02
0.40	0.51	0.64	0.78	0.93	1.10	1.30	1.54	1.90
0.45	0.38	0.52	0.66	0.80	0.97	1.17	1.41	1.77
0.50	0.26	0.38	0.52	0.68	0.84	1.04	1.28	1.64
0.55	0.12	0.26	0.40	0.54	0.71	0.91	1.15	1.51
0.60	0.00	0.13	0.27	0.42	0.58	0.82	1.02	1.38

In addition, The NUREG-1507 report also calculates the $\mathrm{MDCR}_{surveyor}$ by referring to the NUREG/CR-6364 report[3]. In this study, the surveyor efficiency was applied 0.5, as shown in the NUREG-1507 report.

$$\mathrm{MDCR}_{\mathrm{surveyor}}\ (\mathrm{cpm}) = \frac{\mathrm{MDCR\ (cpm)}}{\sqrt{\mathrm{p}}}$$
$$\mathrm{p = surveyor\ efficiency}$$

The MDER(Minimum Detectable Exposure Rate) was calculated using detector sensitivity and $\mathrm{MDCR}_{surveyor}$ as follows.

$$\mathrm{MDER}\ (\mu R/h) = \frac{MDCR_{surveyor}\ (cpm)}{Detector\ sensitivity\ ((cpm/\mu R/h))}$$

In addition, using a correlation of 10cm-high dose rate and concentration of the standard hotspot size(Diameter : 58cm, depth : 15cm), the scan MDC is calculated below.

$$\text{Scan MDC (pCi/g)} = \text{MDER}(\mu\text{R/hr}) \times \frac{\text{C (pCi/g)}}{\text{E } (\mu\text{R/hr})}$$

C = Concentration of soil contamination
E = Exposure rate on source center at 10cm height

2.2 Scan survey experiment

For the scan survey experiment, uniform motion equipment, and small Multi-Channel Analyzer (MCA) Osprey(Canberra) were used. Also, the area source with a diameter of 56cm was made using liquid radioactivity source with soil(Fig.1).

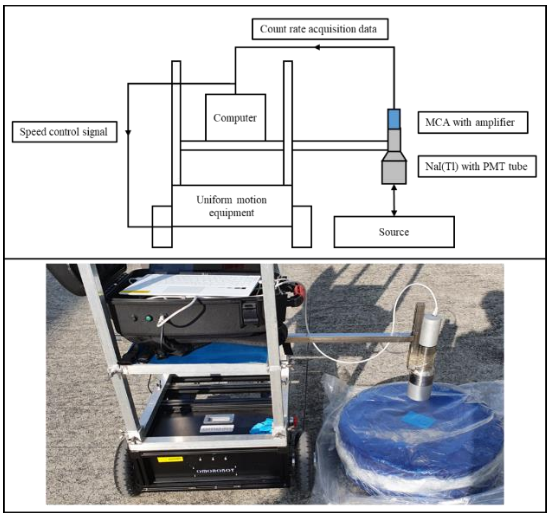


Figure 1 Uniform motion equipment and scan survey system

In addition, the collimator with a thickness of 2cm and an angle of 45° was produced for application to 3 inch NaI(Tl) detector(Fig.2).

Figure 2 45° field of view angle and 2cm thickness collimator for 3inch NaI(Tl) detector

In the experiment, the count rate was measured 10 minutes at the height of 10 cm in the source center for the detector sensitivity calculation. Also, the 3inch NaI(Tl) detector was moved toward the center of the area source at survey speeds of 0.1m/s, 0.3m/s, and 0.5m/s using uniform motion equipment. Then, the count rate(cps) was the acquisition in 0.5 sec to evaluate the count rate for survey location

3. Results

3.1 Assessment of scan MDC

For the calculation of scan MDC, the detector sensitivity of a 3inch NaI(Tl) detector and 3inch NaI(Tl) detector with collimator were evaluated (Table.2).

Table 2 Assessment of detector sensitivity

Detector condition	3inch NaI(Tl) detector with collimator		3inch NaI(Tl) detector	
Isotopes	^{137}Cs	^{60}Co	^{137}Cs	^{60}Co
Exposure rate (μR/h)	1.73	66.2	1.73	66.25
Net count rate (cpm)	1646	46682	2897	70874
Detector sensitivity (cpm/μR/hr)	954	705	1678	1070

As a result of detector sensitivity evaluation, when using a collimator, the sensitivity decreased by 43.15% for ^{137}Cs and 34.11% for ^{60}Co. The exposure rate changing according to the radioactivity concentration of the standard hotspot was evaluated using MCNP simulation. As a result, 4.67 pCi/g/μR/hr for ^{137}Cs and 1.14 pCi/g/μR/hr for ^{60}Co.

The scan MDC is calculated through the detector sensitivity and correlation of radioactivity concentration and exposure rate. The background count rate was measured at the same location(Table.3).

Table 3 Scan MDC changed by collimator

Detector condition	3inch NaI(Tl) detector With collimator		3inch NaI(Tl) detector	
Isotopes	^{137}Cs	^{60}Co	^{137}Cs	^{60}Co
Background count rate (cpm)	11930		42067	
MDCR (cpm)	1651		3101	
MDER (μR/hr)	1.73	2.34	1.85	2.90
Scan MDC (pCi/g)	8.09	2.68	8.63	3.32

As a result, after applying the collimator, the scan MDC was decreased by 6.33% for ^{137}Cs isotope and 19.18% for ^{60}Co isotopes. This result was caused by the differential effect of the collimator on detector sensitivity and background count rate.

When the collimator is applied, the detector sensitivity was decreased. However, the background count rate reduction is more effective. So, the Scan MDC was reduced. Therefore, when a collimator was applied to the scan survey system, it was possible to measure the contamination of lower concentration contamination compared to the same system.

3.2 Assessment of over-estimation reduction performance

The scan survey experiment was conducted on the area source using uniform motion equipment, 3 inch NaI(Tl) detector, and the collimator. Among the measured scan survey results, the number of locations where the count rate higher than MDCR occurred was selected. Also, the estimated source diameter was evaluated in consideration of the scan survey speed.

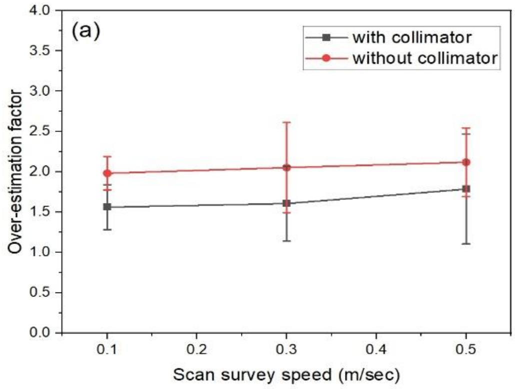
$$\text{Estimated source diameter(cm)} = \mathrm{N} \times \mathrm{S} \times \mathrm{T}$$

N = Number of data point which above the MDCR
S = Scan survey speed (m/sec)
T = Data acquisition time (sec)

Besides, the over-estimation factor was defined to evaluate the degree of overestimation of the estimated area source diameter. The over-estimation factor was calculated based on the actual area source diameter (56cm) as the following equation.

$$\text{Over estimation factor} = \frac{\text{estimated source diameter(cm)}}{\text{actual source diameter(56 cm)}}$$

In the same was as above equation, the over-estimation factor according to the collimator application, scan survey speed, and kinds of radioactive isotopes was evaluated(Fig.3).



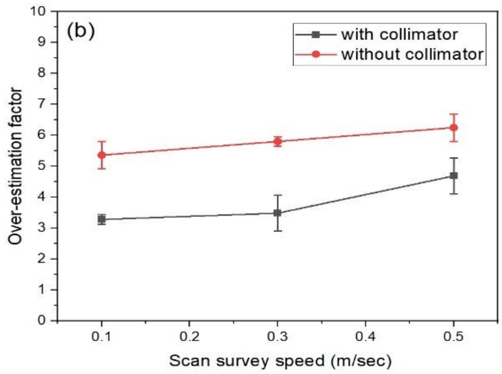


Figure 1 Over-estimation factor change by detector condition and survey speed (a) ^{137}Cs (b) ^{60}Co

As a result, the scan survey speed increased, the size of source tended to be overestimated. This result is because the data acquisition interval increased as the detector speed increased, and it was evaluated that the source was present in the area without source.

Also, the application of the collimator can reduce the over-estimation factor. The reduction rate was between 16~41%, depending on the radioactive isotopes and scan survey speed. This result is because gamma-ray incident the side of the detector from the source were shielded by the collimator. Therefore, the detector is not located above the source, the count rate is reduced by collimator and the points that appear above MDCR value was reduced. Thus, the application of collimator could improve the accuracy of scan survey results.

4. Conclusions

This study was conducted to quantify the performance of the Scan MDC and the degree of over-evaluation reduction of the survey equipment following the collimator's application. For this, 3 inch NaI(Tl) detector and collimator for a 3-inch detector were used. Furthermore, area source was produced using ^{137}Cs and ^{60}Co open sources. The count rate was measured at the 10 cm height in the source center to calculate the detector sensitivity. Calculation of scan MDC based on evaluated detector sensitivity resulted in a reduction scan MDC by 6.33% for ^{137}Cs nuclides and 19.18% for ^{60}Co nuclides by applying collimator.

Also, for the scan survey experiment, uniform motion equipment was used to transport the detector. The Scan Survey speed is 0.1 m/s, 0.3 m/s, and 0.5 m/s, and the data acquisition time is 0.5 sec. The over estimation factor was defined for the quantitative evaluation of an over-estimation degree. The estimated source size was calculated by taking into the number of points assessed above MDCR, data acquisition time, and survey speed. As a result, the over-estimation factor was reduced by about 16~41% depending on the scan survey speed and target isotopes.

Thus, scan survey experiments confirmed that the application of collimator decreases both the Scan MDC and the over-estimation factor. This result proves that performance on the scan survey is improved when using the collimator. In this study, the utility of collimator in the scan survey was evaluated, which is expected to help select the Scan Survey method and equipment.

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