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# Feasibility of a NaI(Tl) Scintillation Bar Detector for Measurement of Radioactive Contamination

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Feasibility of a NaI(Tl) scintillation bar detector for the measurement of radioactive contamination has been studied. The scintillator has dimensions of 6.35×6.35×71.12cm$^3$. Its surface is polished to obtain the information of position. Two photomultiplier tubes (PMTs) are mounted on both sides of the bar scintillator. The position where an incident gamma-ray interacts with the scintillator is determined from the difference of light output between the two PMTs. The energy distribution deposited in the scintillator is obtained by summing up the output signals. For a collimated $^{60}$Co source, the position and energy resolutions at the center of bar detector were 3.1cm ( FWHM ) and 6.3% at the energy of 1.33MeV, respectively. For a collimated $^{137}$Cs source, the resolutions were 3.4cm and 9.8%, respectively. For the $^{60}$Co point source, the lead plates of 1cm thick and 10cm length were used as a collimator with the intervals of 5cm in order to prevent the spatial extent of radiation. Then, the source position placed at a distance of 10cm was identified within the intervals. These results show that the information of energy and position of radioactive contamination can be obtained using the simple bar detector.

***KEYWORDS: radioactive contamination, NaI(Tl) scintillator, bar detector, position resolution, energy resolution, gamma-ray, collimator***

## I. Introduction

In the evaluation of radioactive contamination on the floors of a nuclear facility and on the large articles carried out from a radioactive controlled area, it is important to measure the position of radioactive contamination and to determine radioactive nuclides. Usually, the measurement of surface contamination is conducted with a beta-ray detection system. For some nuclides (e.g. $^{54}$Mn), however, it is difficult to apply the beta-ray detector. When the contamination penetrates into a measured object, the measurement of beta-ray becomes difficult due to the surface condition of a object to be measured. Such cases require the measurement of gamma-ray. If the photopeaks of gamma-ray are measured, the nuclides that cause the contamination can be simply determined. In the efficient measurement for the large contamination area, the detection system with a large detection area and/or an array structure is required.[1, 2, 3] Such a system usually needs many electronics and thus a simple system would be preferable.

In order to obtain the information of positions and gamma-ray energies with a relatively simple system, the feasibility of a NaI(Tl) scintillation bar detector has been studied. This paper describes the characteristics of bar detector on the position and energy resolutions and its feasibility for the measurement of radioactive contamination.

## II. NaI(Tl) Scintillation Bar Detector

NaI(Tl) scintillation bar detectors have been applied to gamma-ray imaging telescopes[4, 5] and computed tomography (CT) instruments.[6] The bar detector has two photomultiplier tubes (PMTs) on both sides. When a photon interacts with the scintillator at a position of the bar detector, the scintillation light measured at one end of the bar is attenuated according to the distance between the interaction position and the PMT. Hence, the position where an incident gamma-ray interacts with the scintillator can be determined from the difference of light output between the two PMTs. The optimization of the detector design was studied by Carter et al..[4] According to the literature, the optimum position resolution depends on the detector length and the light attenuation coefficient per length. In the application of bar detector to the telescope and the CT instrument, the high-resolution detector with the position resolution of a few millimeters has been required. Because the attenuation coefficient varies according to the reflectance of scintillator surface and the dimensions on its cross-section, the dimensions of scintillator are constrained by the coefficient. If the dimensions of bar detector are determined in advance, the adjustment of light attenuation coefficient is required to optimize the position resolution. If the length increases, the attenuation coefficient must be reduced. It is difficult to prepare the high-resolution bar detector with the length exceeding an adjustable limit of attenuation coefficient.

In the measurement of radioactive contamination for the large area, the high-resolution detector on the position is not necessary. In this study, the dimensions of bar detector were determined for the convenience of handling. The position resolution was not optimized, but the surface of scintillator was polished to obtain the information of position by the attenuation of scintillation light inside itself. **Figure 1** shows the schematic drawing of the measuring system with the bar detector unit. The scintillator has dimensions of 6.35 × 6.35 × 71.12cm$^3$. The effective length is 69cm excluding both sides of the detector which are covered with the thick aluminum case. The surface of the scintillator is covered with an alu-

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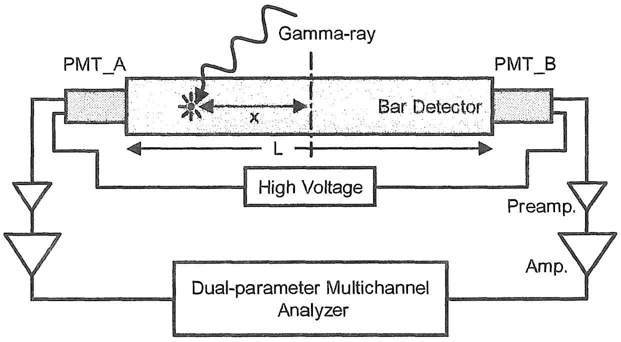



**Fig. 1** Schematic drawing of NaI(Tl) scintillation bar detector unit and measuring system

minum case of 1mm thick. Two photomultiplier tubes (PMTs) with a diameter of 5.08cm are mounted on both sides of the bar scintillator. The distribution of energy deposited in the scintillator is obtained by summing up the output signals from both PMTs. The signals from the PMTs were measured with a dual-parameter multichannel analyzer. Therefore, the interaction position and the deposited energy were concurrently evaluated with the simple measuring system, and such information could be perceived visually. The pulse-height distributions from the PMTs were recorded in the memory of 1024 channels.

In this study, the intrinsic position and energy resolutions for the bar detector were measured and evaluated with collimated sources. Apparent position resolutions of the detector were also measured with point sources, and an experiment to determine the position of radioactive contamination was conducted.

## III. Results and Discussion

### 1. Position and Energy Resolutions for Collimated Sources

When the coincident signals from two PMTs were recorded with the dual-parameter multichannel analyzer, the result was shown as two-dimensional plots. As an example of plots, the detector response to a collimated $^{60}$Co source is shown in **Fig. 2**. The figure is illustrated as the synthetic result of responses measured at the intervals of 5cm along the detector axis. The data of 1024 channels were compressed into that of 256 ones. The X and Y axes show the pulse-heights from the PMT_B and the PMT_A, respectively. When a photon interacts with the scintillator at a distance x from the center of the bar scintillator of length L (**Fig. 1**), the signals $E_A$, $E_B$ at both PMTs are given by

$$E_A = C_E e^{-\alpha(L/2-x)}, \tag{1}$$

$$E_B = C_E e^{-\alpha(L/2+x)}, \tag{2}$$

where $\alpha$ is the light attenuation coefficient per length, $C_E$ is the signal given as a light quanta at the interaction position. From equation (1) and (2), the relationship among both signals and the interaction position x can be described by

$$\frac{E_A}{E_B} = e^{2\alpha x}. \tag{3}$$

Equation (3) shows that all the coordinates with the same ratio of $E_A/E_B$ denote the same interaction position of bar detector. For example, the straight line given in **Fig. 2** shows that the interaction position is the center of detector (hereafter the center position is treated as the position of 0cm). The equation can be also rewritten as the following equation with angle $\theta$ between the line and the X-axis.

$$\theta = \tan^{-1}\left(e^{2\alpha x}\right). \tag{4}$$

From equation (4), the relationship between the interaction position x and the angle $\theta$ can be determined. The distribution of the counts on the line gives the pulse-height distribution.

In **Fig. 2**, the curve passing through the coordinates corresponding to the same energy (e.g. 1.33MeV) should be symmetric to the position of 0cm. However, the present detector has a different response around the edges of the detector. The main reason would be the difference of the sensitivity for scintillation light between the PMT_A and PMT_B due to the asymmetry coupling between the NaI(Tl) crystal

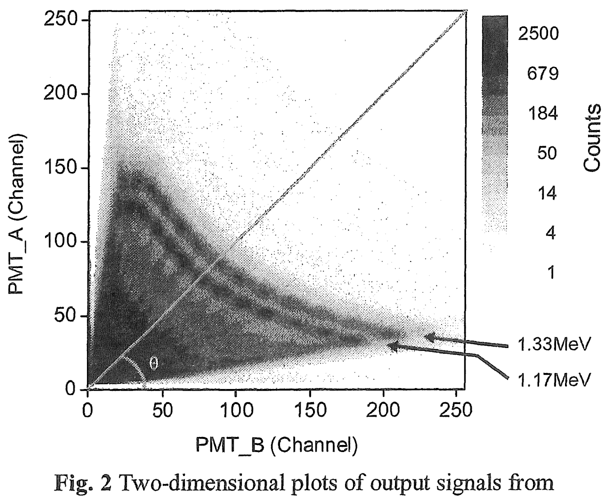
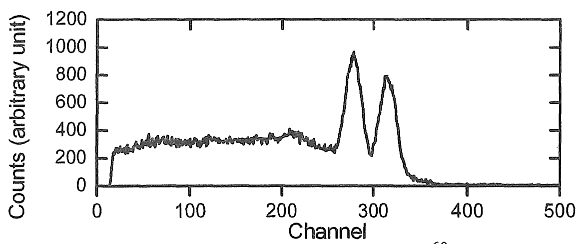
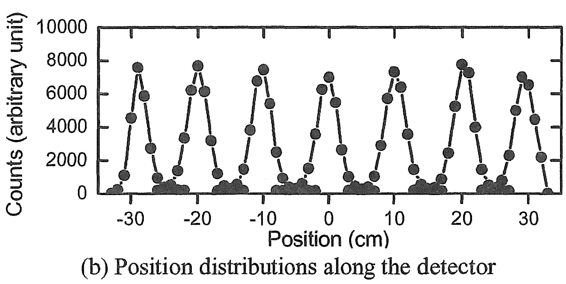



**Fig. 2** Two-dimensional plots of output signals from bar detector




(a) Pulse-height distribution for collimated $^{60}$Co source




(b) Position distributions along the detector

**Fig. 3** Energy and position distributions and the light window.

The pulse-height distribution for the collimated $^{60}Co$ source placed at the position of 0cm is shown in **Fig. 3 (a)**. **Figure 3 (b)** shows the position distributions along the detector on the 1.33MeV photopeak for the collimated source placed at each 10cm interval. These position resolutions obtained with the collimated sources are the intrinsic characteristics for the bar detector unit. At the position of 0cm, the energy and position resolutions evaluated from the FWHMs were 6.3% and 3.1cm at the energy of 1.33MeV, respectively. For a collimated $^{137}Cs$ source, the energy and position resolutions at the position of 0cm were 9.8% and 3.4cm, respectively. For the collimated $^{60}Co$ source, the position resolutions were agreed within 7% in the range from –20cm to 20cm. For the $^{137}Cs$ source, the resolutions were also within 7%.

## 2. Determination of Source Position with Collimator Plates

In the case of actual situation, it becomes difficult to determine the source position from the position distribution because the distribution corresponds to the intensity distribution of incident gamma-ray depending on the distance between the detector and the source. **Figure 4** shows the position distributions for the 1.33MeV photopeak. The $^{60}Co$

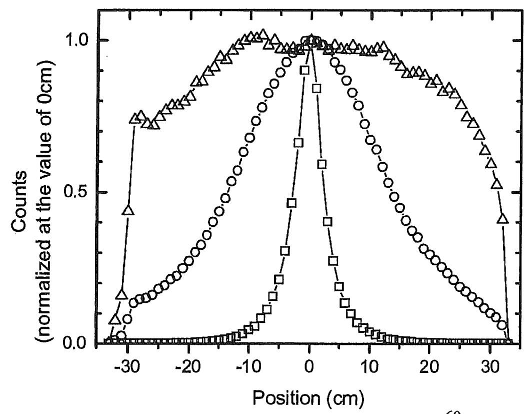



**Fig. 4** Position distributions for uncollimated $^{60}Co$ source placed at various distances
The squares, circles and triangles show the distances of 0, 10 and 40cm, respectively.

point source was placed at the distance of 0, 10 or 40cm above the position of 0cm. The apparent position resolutions evaluated from the distributions for the distances of 0 and 10cm were 5.2cm and 32.3cm, respectively. For the distance of 40 cm, it was impossible to evaluate the apparent position resolution as the FWHM. As shown by **Fig. 4**, the position resolution given as the FWHM becomes poorer with increasing the distance between the detector and the source. On the other hand, sum effect grows with decreasing the distance for cascade photon emitters.

From the reasons above, the bar detector needs a collimator to prevent the spatial extent of radiation, and, when there are the nuclides emitting the cascade gamma-ray in the radioactive contamination, it is also important that the detector

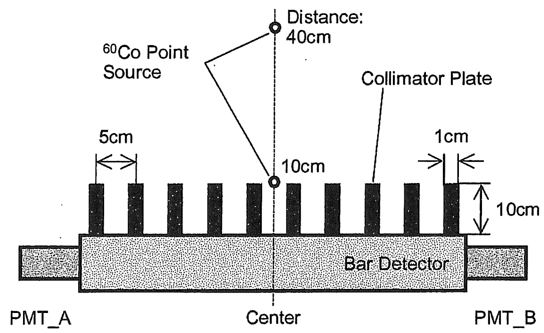



**Fig. 5** Schematic drawing of arrangement among collimator plates, bar detector and $^{60}Co$ point source

is kept away from the contamination position to reduce the sum effect. In order to meet both requirements, we applied a collimator to the bar detector. The collimator with the intervals of 5cm was prepared with lead plates of 1cm thick and 10cm length. The arrangement of the collimator plates is shown in **Fig. 5**. The measurement for the $^{60}Co$ point source placed at the distance of 10 or 40cm above the position of 0cm was conducted with the collimator plates. The arrangement among the source, the collimator and the bar detector is also given in **Fig. 5**. The comparison of position distributions between without and with the collimator plates is shown in **Fig. 6**. In the figure, the distributions measured with the collimator are given as histograms with the intervals of 5cm. For the distance of 10cm, the source position was identified within the intervals. When the apparent position resolution was evaluated as the FWHM from the position distribution, the resolution measured with the collimator plates was about one sixth in comparison with that without them. For the distance of 40cm, while it is difficult to determine the source position without the collimator plates, it has become possible to determine the source position within about 25cm with the collimator. The collimator plates allowed the determination of contamination position in a few tens of cm from the detector.

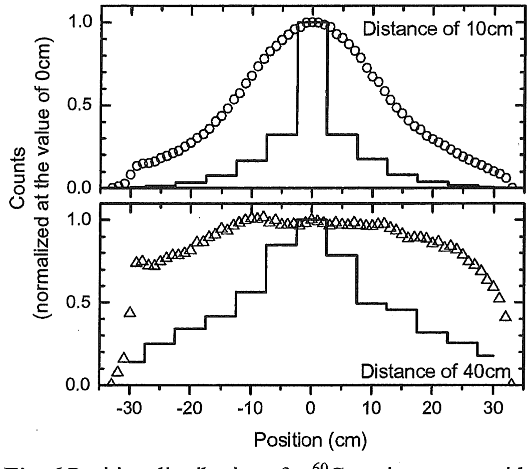



**Fig. 6** Position distributions for $^{60}Co$ point source without and with the lead collimator plates
The circles and triangles show the distributions without collimator plates, and the solid histograms show with one.

From the results mentioned above, it was made up clear that the NaI(Tl) scintillation bar detector made it possible to determine the radioactive contamination position.

### 3. Consideration in Application of the Bar Detector to Contamination Monitor

When the bar detector is applied to the measurement of the contamination, the influence of sum effect should be considered. In the measurement of gamma-ray peaks and the evaluation of radioactivity, the sum peak increases the uncertainty. **Figure 7** shows the difference of sum effect due to the position where the $^{60}$Co point source is placed. The

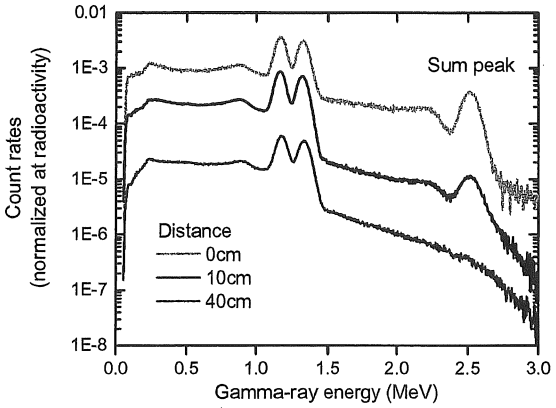



**Fig. 7** Sum effect for cascades

source was placed at the distance of 0, 10 or 40cm above the position of 0cm. The measurement was conducted without the collimator plates. The pulse-height distribution was normalized on the radioactivity of source. For the nuclides emitting the cascade gamma-rays, it is desirable to reduce the probability of sum effect. For the $^{60}$Co source placed at the distance of 0cm, the ratio of the sum peak counts to the 1.33MeV peak ones reached 19%, while, when the distance between the source and the detector increased to only 10cm, the ratio reduced to 2%.

In the actual measurement, the detection efficiency is also the important factor. The distance and the collimator affect the efficiency. When the distance between the source and the bar detector increased from 0cm to 10cm, the detection efficiency without the collimator plates for the 1.33MeV photopeak area was reduced by about 70%. On this condition of source position, the collimator plates were applied to the bar detector. **Table1** shows the ratio of detection efficiency between without and with the collimator plates. The efficiency with the collimator plates was reduced by about 60%

**Table1** Comparison of detection efficiency between without and with collimator plates

| Distance (cm) | Without collimator plates | With collimator plates |
|---|---|---|
| 10 | 0.017 | 0.0066 |

compared to without them. Improvement of position resolution is accompanied by the reduction of detection efficiency.

If the aimed nuclide is a single photon emitter, there is no little influence of sum effect to the result of measurement. If the suitable collimator plates are selected depending on the aimed nuclides, the bar detector is effectively applicable to the measurement of radioactive contamination.

## IV. Conclusion

The feasibility of NaI(Tl) scintillation bar detector for the measurement of radioactive contamination has been studied. When the intrinsic position and energy resolutions were measured along the bar detector with the collimated source, they were comparatively constant excluding both sides of detector where the coupling between the NaI(Tl) crystal and the light window would be incomplete. In order to determine the point source position, collimator plates with the intervals of 5cm were applied to the bar detector to prevent the spatial extent of radiation. Then, the $^{60}$Co source position placed at a distance of 10cm was identified within the intervals. These results shows that the information of energy and position of radioactive contamination can be obtained using the simple bar detector.

When the distance from the contamination position and the suitable collimator plate are selected depending on the aimed nuclides, the bar detector can be effectively used as the contamination monitor.

### References


1) H. Ezure, S. Miyasaka and H. Kuroda, et al., "Measurement of Residual Radioactivity in the Facility Being Decommis sioned," *Proc. the Second Workshop on Residual Radioactiv ity and Recycling Criteria Jointly Spnsored by the United States Environmental Protection Agency the Office of Radia tion and Indoor Air, and the Japan Atomic Energy Research Institute*, JAERI-Conf 95-015 (1995).
2) I. Auler, E. Neukäter and M. Franz, et al., "Release Measure ments for Materials Out of Controlled Areas," *Appl. Radat. and Isot.*, **53**, 331 (2000).
3) S. Makino, T. Yamanaka and T. Sumita, et al., "Verification test of radioactivity distribution measurement techniques for the surface of buildings," *Proc. of the 7th Int. Conf. on Nu clear Engineering*, Tokyo, Japan, Apr. 19-23, 1999, p. 4252 (1999).
4) J. N. Carter, P. Charalambous and A. J. Dean, et al., "A Position Sensitive Detector for a Gamma-ray Imaging Tele scope," *Nucl. Instr. and Meth.*, **196**, 477 (1982).
5) A. J. Court, A. J. Dean and M. Yearworth, et al., "A Position Sensitive Detector Using a NaI(Tl) / Photomultiplier Tube Combination for the Energy Range 200 keV to 10 MeV," *Nucl. Instr. and Meth.*, **A273**, 706 (1988).
6) B. J. Maddox, J. M. Galvin and K. R. Kase, et al., "A One-dimensionally Position-sensitive Scintillation Detector," *Nucl. Instr. and Meth.*, **190**, 377 (1981).