Measuring Radioactivity of ^{90}Sr based on Cherenkov Radiation in Real Time

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***Abstract*—In March, 2011, a nuclear accident of the Fukushima Daiichi Nuclear Plant occurred, which radioisotopes spread around Japan and the Pacific Ocean. The inspection of ^{90}Sr concentration for sample in real time (or rapidly) is focused by a recent study. We are developing a detector to measure the radioactivity concentration of ^{90}Sr in sample based on Cherenkov light using silica aerogel. The detector performance was estimated by using radiative source such as ^{90}Sr, ^{137}Cs, and ^{40}K. As a result, the detection efficiency of other nuclides (^{137}Cs and ^{40}K) is enough less than that of ^{90}Sr for contamination inspection.**

***Index Terms*—Beta-ray Detectors, Cherenkov Detectors, Radiation Environment, Strontium-90**

I. Introduction

In March, 2011, a nuclear accident of the Fukushima Daiichi Nuclear Plant occurred, which radioisotopes spread around Japan and the Pacific Ocean [1]. Recently after late 6 yr since the accident, It has been a problem the radioactivity contamination of seafood by isotope such as ^{137}Cs and ^{90}Sr, which have relatively long half life [2], [3]. Recent study is focuses to method how to measure radioactivity concentration of ^{90}Sr for the sample in real time or rapidly [4]. We are developing a detector to measure the concentration of ^{90}Sr based on Cherenkov detection [5]–[7]. In this paper, the detector overview and performance is provided.

II. Detector Overview

The detector to measure the radioactivity of ^{90}Sr consists of a trigger counter using scintillating fibers, a threshold type Cherenkov counter using silica aerogel and wavelength-shifting fibers, and a veto counter to suppress events originated cosmic rays using plastic scintillator and wavelength-shifting fibers. The prototype with an effective area of 300 $times$ 100 cm^2 was produced [5]. Strontium-90 decays to ^{90}Y with emitting a beta ray with max. kinetic energy of 0.55 MeV (half life of 28.8 y), and ^{90}Y decays to stabled ^{90}Zr with emitting a beta ray with max. kinetic energy of 2.28 MeV. Strontium-90 and ^{90}Y become to radiation equilibrium condition, and ^{90}Sr radioactivity approximates to ^{90}Y that. The silica aerogel with a refractive index of 1.041±0.001 [9] is used in the detector for suppress events related beta rays emitted from ^{40}K as background. The detector can observe only beta rays related ^{90}Y in principle because Cherenkov photons are emitted when the relation between charged particle velocity ratio $\beta = v/c$ and the refractive index n satisfy $\beta > 1/n$, where relation between β, electron mass m, and kinetic energy of beta ray K is given as,

$$\beta = \frac{\sqrt{(m+K)^2 - m^2}}{m+K} \tag{1}$$

As the limit of detector, the background rate is determined by accidental noise such as gamma rays with energy over few MeV.

III. Performance Estimation

The results of count rates for ^{90}Sr, ^{137}Cs, ^{40}K, and no source are shown in Fig. 1. The black, red, green, and blue histograms are, respectively, no source, ^{137}Cs of 1 kBq, ^{40}K of 1 kBq, ^{90}Sr of 1 kBq. The background rate without radioactive source (black) is estimated 35.2±6.0 h$^-$1, where the histogram represents a total 60 times of 1 h measurement. The count rate of ^{90}Sr, ^{137}Cs, and ^{40}K (blue, red, green) are estimated $(4.14 \pm 0.39) \times 10^3$ h$^-$1, 41.5 ± 5.5 h^{-1}, 54.7 ± 7.6 h^{-1}. As a result, in the same radioactivity, the detector has higher sensitivity to ^{90}Sr than ^{137}Cs and ^{40}K.

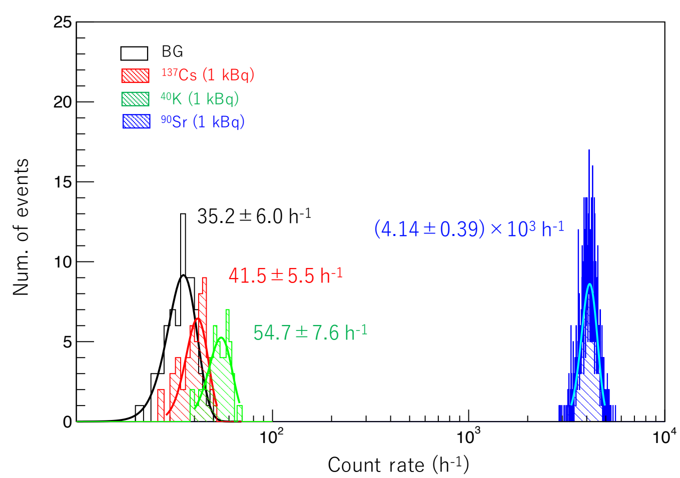

Fig. 1. The count rate for ^{90}Sr, ^{137}Cs, ^{40}K, and no source.

Here, the detection limit is discussed. The models reproducing experimental signals are shown in Fig. 2. The red and green lines reproduce the signal for background and the ^{90}Sr radioactivity of 40, 80, 120, 160, 200 Bq/kg. It assume that

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the detection efficiency is defined as a percentage when signal of ^{90}Sr radioactivity is 3 σ higher than mean of background rate, i.e., the threshold is 3 σ. The relation between 90Sr radioactivity and the detection efficiency for threshold of 1, 2, and 3 σ is shown in Fig. 3. As a result, efficiency of 99% is 92 Bq/kg (3 σ), 75 Bq/kg (2σ), 58 Bq/kg (1 σ) in measuring time of 1 h. These detection efficiency curves are provided as the detector performance.

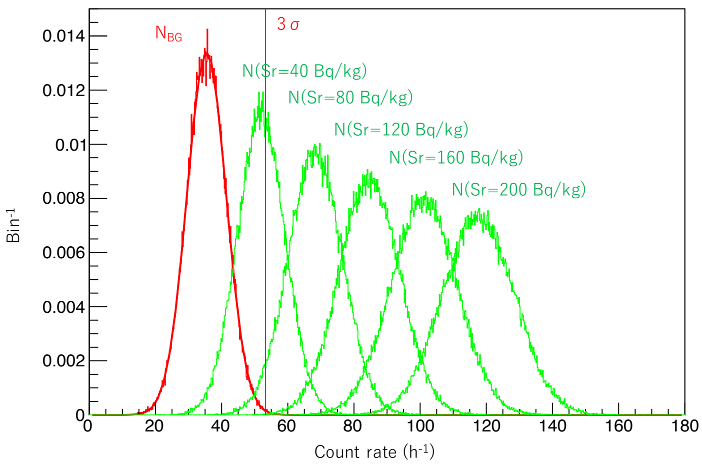

Fig. 2. The models reproducing the experimental signals.

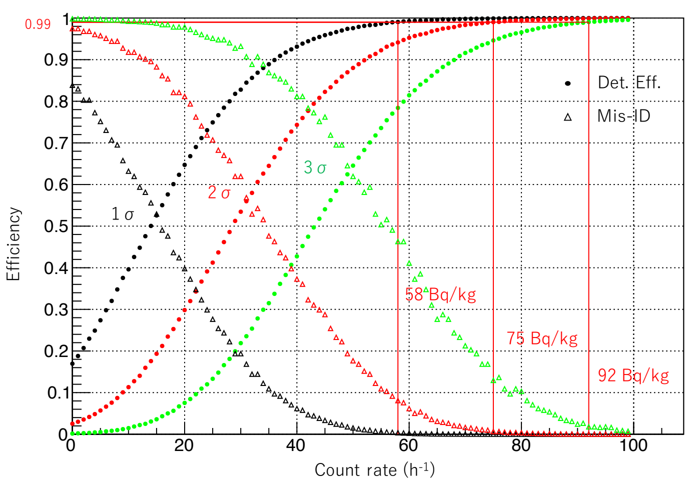

Fig. 3. The relation of ^{90}Sr radioactivity and the detection efficiency of each threshold and the relation between the radioactivity and mis-identification of no ^{90}Sr sample.

IV. Results and Conclusion

We are developing the detector to measure ^{90}Sr radioactivity concentration based on Cherenkov radiation detection. It was found the detector has higher sensitivity of ^{90}Sr than ^{137}Cs and ^{40}K. The detection efficiency curves represents the detector performance. The measurement limit can be determined by a threshold and mount of the efficiency decided in the curve.

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