Identification of ^{90}Sr and ^{40}K based on Cherenkov Radiation at lower background suppressed Cosmic rays

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abstract

A new detector, real-time ^{90}Sr counter, was developed with sensitivity of ^{90}Sr and insensitivity of ^{137}Cs, ^{40}K and Cosmic rays, based on Cherenkov radiation. The detector is threshold type Cherenkov counter using silica aerogel with a refractive index of 1.042. Since of the threshold energy of 1.31 MeV, the beta-ray from ^{90}Y can be identified. This detector would be applied for recovery Fukushima. By the Fukushima Nuclear Accident in 2011, particularly the fisheries were severely damaged due to radioactive contamination in Fukushima, Japan. Recent study is focus to radiation with longer half-life, ^{90}Sr and ^{137}Cs, in the contaminated water. The performance of the detector was evaluated as an absolute efficiency using ^{90}Sr, ^{137}Cs and KCl source; as the result, the efficiency of ^{90}Sr, ^{137}Cs and ^{40}K are obtained $(2.24 \pm 0.02) \times 10^{-3}\ \mathrm{Bq^{-1}sec^{-1}}$, $(1.27 \pm 0.23) \times 10^{-6}\ \mathrm{Bq^{-1}sec^{-1}}$ and less than $1.6 \times 10^{-4}\ \mathrm{Bq^{-1}sec^{-1}}$, respectively. The detector was estimated the detection limit of ^{90}Sr of 45 Bq/kg for seafood and 1.6 Bq/kg for seawater.

1. Introduction

By the Fukushima Nuclear Accident in 2011, particularly the fisheries were severely damaged due to radioactive contamination in Fukushima, Japan. Recent study is focus to radiation with longer half-life, ^{90}Sr and ^{137}Cs, in the contaminated water. It was reported that radioactivity of isotope of cesium (radio-cesium) was measured in sample of fish and estuary sediments around Fukushima in Japan [1, 2]. It is more dangerous for internal exposures to take ^{90}Sr than ^{137}Cs because effective half-life of ^{90}Sr and ^{137}Cs in the body are 18 years and 70 days, respectively. The effective half-life (τ_{eff}) is defined as,

$$\tau_{eff}^{-1} = \tau_{phys}^{-1} + \tau_{bio}^{-1},$$

where τ_{phys} is the physical half-life and τ_{bio} is the biological half-life.

We have developed a new detector, real-time ^{90}Sr counter, with sensitivity of ^{90}Sr and insensitivity of ^{137}Cs, ^{40}K and Cosmic rays, based on Cherenkov radiation. The paper presents the mechanism of the detector and the results for the performance evaluation using radioactive source and estimation of detection limit for ^{90}Sr.

2. Real-time ^{90}Sr Counter

A new detector, real-time ^{90}Sr counter, was developed based on Cherenkov radiation [3]. The detector has some advantage: (1) easily to handle similar of a Survey meter, (2) rapidly to measure for an hour, (3) to use anywhere without the radiation controlled area, (4) to make a sample without chemical extraction. The detector consists of a trigger counter made of scintillating fibers (SFT), an aerogel Cherenkov counter with wavelength shifting fibers (AC) and a veto counter made of plastic scintillator and wavelength shifting fibers (veto). The detector is threshold type Cherenkov counter using the silica aerogel with a refractive index of 1.042. Since threshold energy is 1.31 MeV, the beta-ray from ^{90}Y can be identified. We have produced a prototype detector with an effective area of $300\ \mathrm{mm} \times 100\ \mathrm{mm}$.

(a) Mechanism of detection based on Cherenkov radiation

Cherenkov radiation is a kind of shock wave. When velocity of a charged particle is higher than light velocity in a material with a refractive index of n, photons are emitted. In order to emit Cherenkov photons for only beta-rays from ^{90}Y [4], silica aerogel [5] with the index of 1.042 was used. Table 1 lists the decay mode, the maximum of kinetic energy ($K_{\beta max}$) of beta-rays, energy of gamma-rays (E_γ) and blanching ratio. Fig. 1 shows a relation of threshold of kinetic energy and the index for electrons in the Cherenkov condition.

Decay mode	$K_{\beta max}$		E_γ	
$^{90}Sr \rightarrow {}^{90}Y$	0.546 MeV	(100%)		
$^{90}Y \rightarrow {}^{90}Zr$	2.28 MeV	(100%)		
$^{137}Cs \rightarrow {}^{137}Ba$	0.512 MeV	(94.6%)	0.622 MeV	(94.6%)
	1.174 MeV	(5.4 %)		
$^{134}Cs \rightarrow {}^{134}Ba$	0.658 MeV	(70.2%)	0.604 MeV	(97.6%)
	0.089 MeV	(27.3%)	0.796 MeV	(85.5%)
			0.802 MeV	(8.7%)
			0.563 MeV	(8.4%)
$^{40}K \rightarrow {}^{40}Ca$	1.311 MeV	(89.3%)		
$^{40}K \rightarrow {}^{40}Ar$			1.461 MeV	(10.7%)

Table 1. Maximum kinetic energy of beta-rays, energy of gamma-rays from min radionuclides with their blanching ratio.

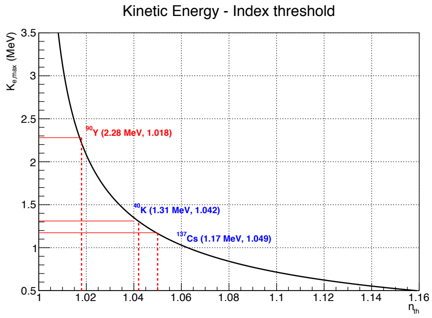

Fig. 1. Relation of threshold of kinetic energy of beta-rays and the index in ^{90}Y, ^{137}Cs and ^{40}K.

(b) Design of the detector

Fig. 2 shows the design of the detector. When the condition of the counts by $SFT \cap AC \cap \overline{veto}$, charged particles with kinetic energy over 1.31 MeV from a sample were detected. Wavelength shifting fibers (WLSFs) was used two types (Y-11 and B-3), because of well collecting efficiency for Cherenkov photons. The WLSFs were installed over the silica aerogel for reading Cherenkov photons instead of a bigger PMT (Fig. 3). The veto counter covers the SFT and the AC to suppress the events of Cosmic rays.

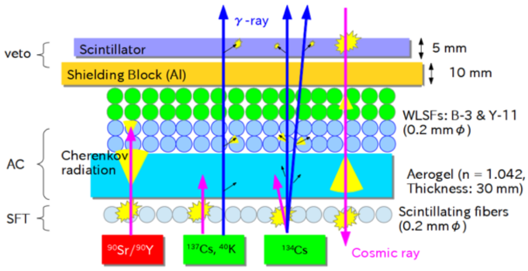

Fig. 2. The design of Real-time ^{90}Sr counter. It consists SFT, AC and veto.

Fig. 3. Relation of threshold of kinetic energy of beta-rays and the index in ^{90}Y, ^{137}Cs and ^{40}K.

3. Results

The performance of the detector was evaluated by using radioactive source of ^{90}Sr, ^{137}Cs and KCl. The source was set under the detector to count number of a scalar for an hour at 10 times. An absolute efficiency was defined as a ratio of number of count rate and radioactive of source; as the result, the the efficiency of ^{90}Sr, ^{137}Cs and ^{40}K are obtained $(2.24 \pm 0.02) \times 10^{-3}\ \mathrm{Bq^{-1}sec^{-1}}$, $(1.27 \pm 0.23) \times 10^{-6}\ \mathrm{Bq^{-1}sec^{-1}}$ and less than $1.6 \times 10^{-4}\ \mathrm{Bq^{-1}sec^{-1}}$, respectively. The detector was estimated the detection limit of ^{90}Sr of 45 Bq/kg for seafood and 1.6 Bq/kg for seawater.

4. Conclusion

We have developed a new detector, real-time ^{90}Sr counter, based on Cherenkov radiation for recovery of Fukushima fishery and monitoring contaminated water. The prototype detector was evaluated the performance using the source, and the detection limit of ^{90}Sr was estimated. Recently, next detector with the effective area of $500\ \mathrm{mm} \times 200\ \mathrm{mm}$ is developing to improve the performance.

Reference

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