INTERNATIONAL CONFERENCE on ADVANCEMENTS in NUCLEAR INSTRUMENTATION MEASUREMENT METHODS and their APPLICATIONS (ANIMMA 2017)
PALAIS DES CONGRES, LIEGE, BELGIUM, 19-23, June, 2017

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

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Abstract —The inspection of ^{90}Sr concentration for a 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 a sample based on Cherenkov light using silica aerogel. The detector performance was estimated by using radiative sources.

Introduction

- In March, 2011, A Nuclear Accident of the Fukushima Daiichi Nuclear Plant occurred [1].
- It is difficult to inspect the ^{90}Sr contamination of raw-fresh foods sample for the chemical extraction method in conventional because it takes a few weeks – about month to measure [2].
- The inspection of ^{90}Sr concentration for sample in real time (or rapidly) is focused by a recent study [3].
- We have been developing a detector to measure the radioactivity concentration of ^{90}Sr in sample based on Cherenkov light using silica aerogel [4-6].
- The study presents the detector signal model development and the suppression of environmental radiation by external shielding.

Signal Model Development

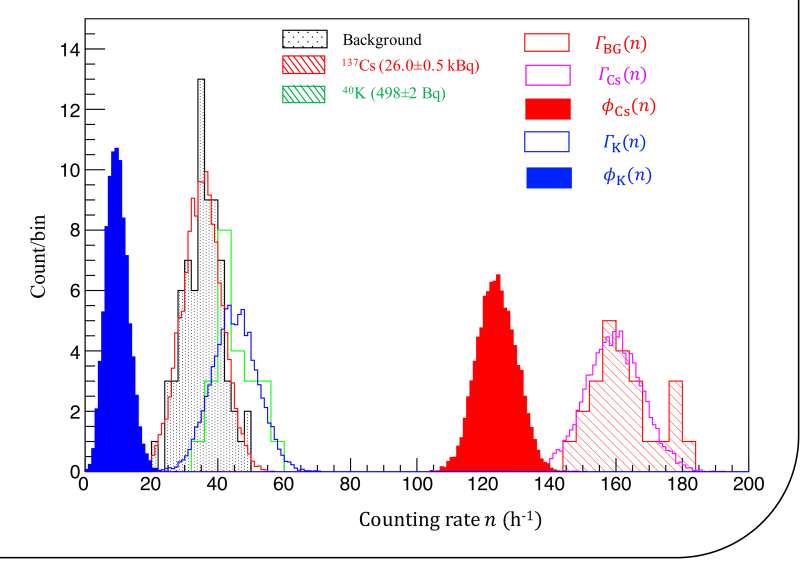
Detector background model $\Gamma_{\mathrm{BG}}(n)$ and the signal model $\phi_x(n)$ without background and the signal model $\Gamma_{\mathrm{x}}(n)$ with the background were developed based on experimental data given as

$$\Gamma_{\mathrm{BG}}(n) = \frac{1}{\sqrt{2\pi\sigma_{\mathrm{BG}}^2}} \exp\left(-\frac{(n-\nu_{\mathrm{BG}})^2}{2\sigma_{\mathrm{BG}}^2}\right), \quad \phi_x(n) = \frac{e^{-\nu/\alpha^2}(\nu/\alpha^2)^{n/\alpha^2}}{\Gamma(n/\alpha^2+1)},$$

$$\Gamma_x(n) = \int d\tilde{n}\, \phi_x(\tilde{n}) \cdot \Gamma_{\mathrm{BG}}(\tilde{n}-n),$$

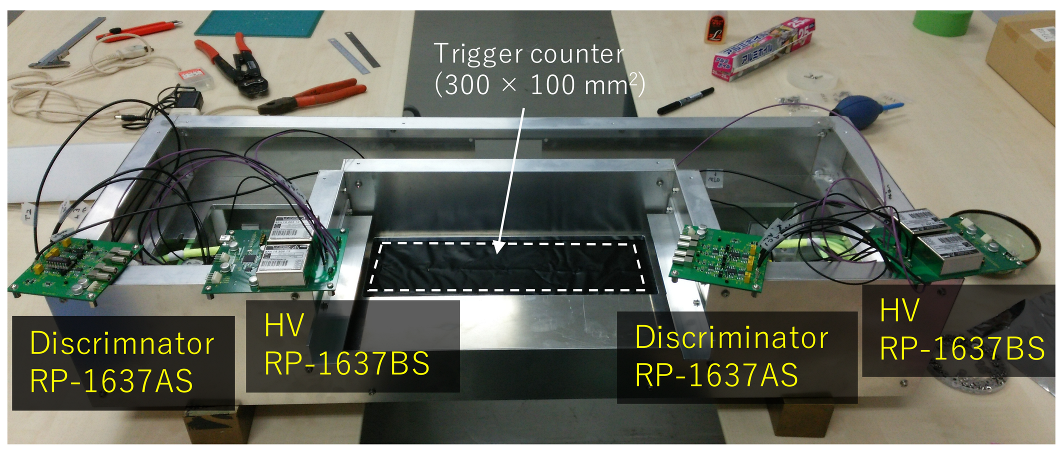
where n is the number of counting rate, $\nu = kA$, A is radioactive intensity, k is the coefficient (Bq^{-1} h^{-1}), and $\Gamma(n)$ is the Gamma function.

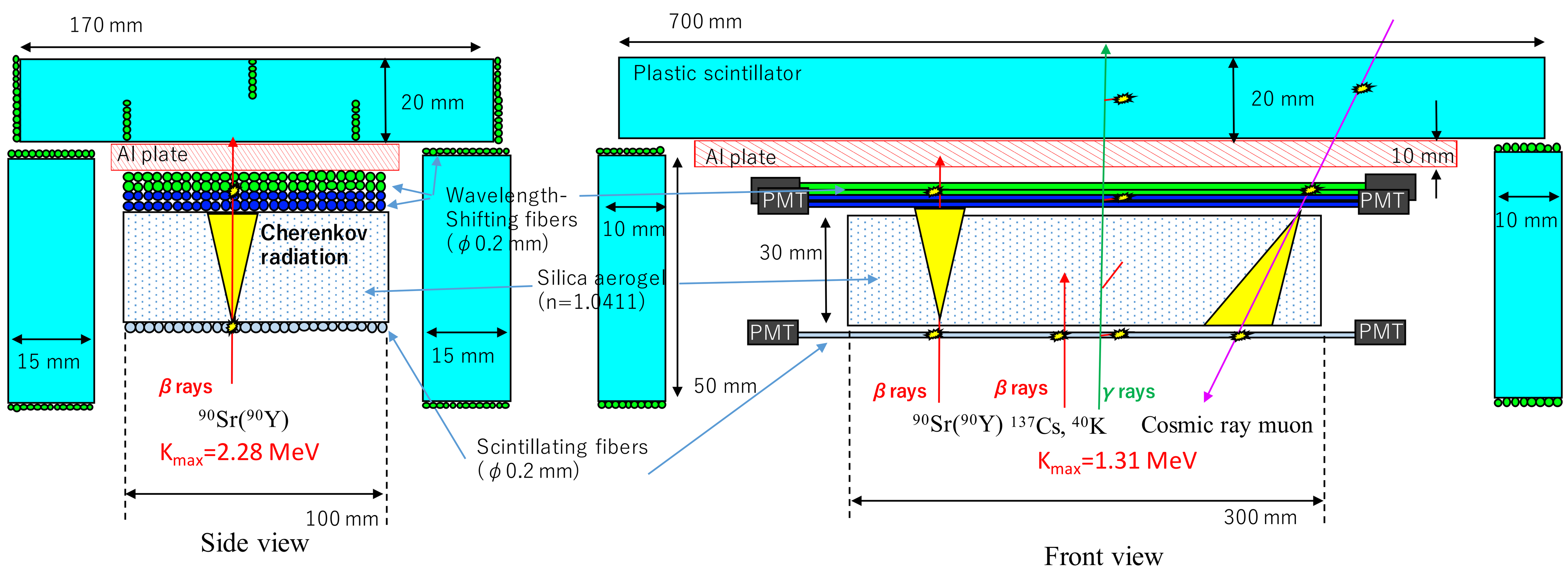
Source	α	k
^{90}Sr	2.50 ± 0.50	(6.23 ± 0.13) Bq^{-1} h^{-1}
^{137}Cs	0.532 ± 0.044	$(4.77 \pm 0.09) \times 10^{-3}$ Bq^{-1} h^{-1}
^{40}K	1.067 ± 0.106	$(1.95 \pm 0.04) \times 10^{-2}$ Bq^{-1} h^{-1}



Detector Overview

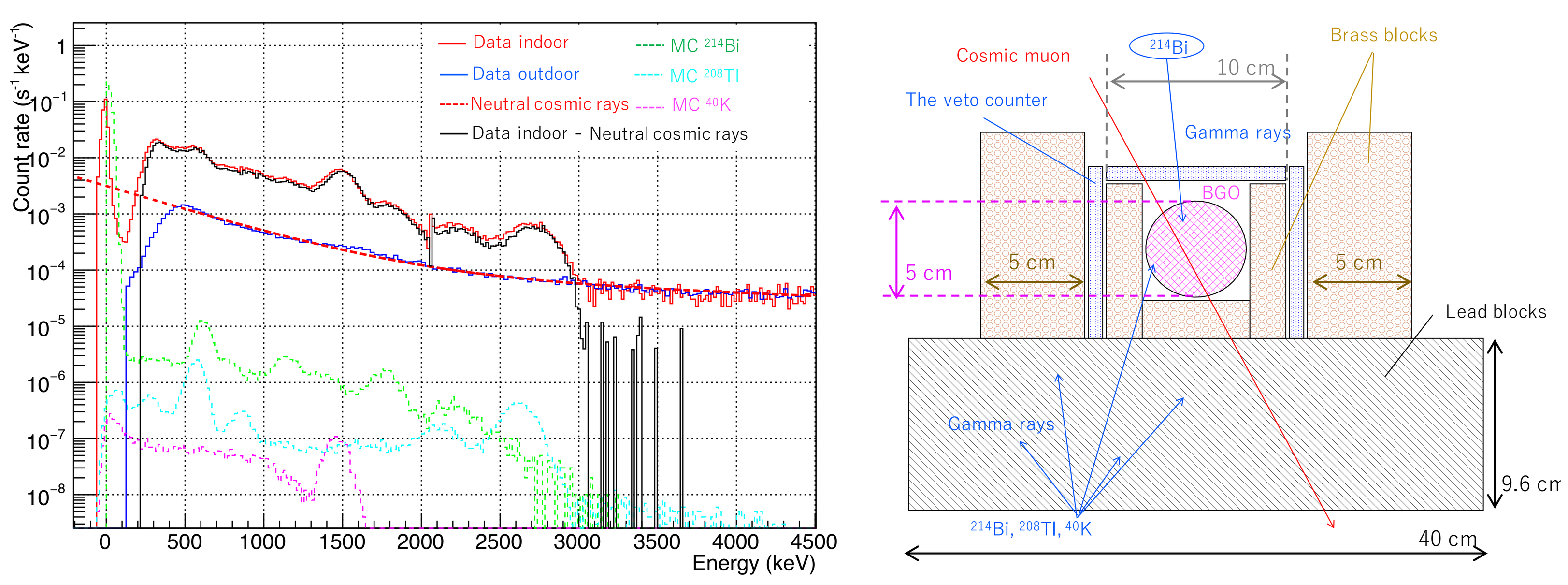
- A Threshold-type Cherenkov detector using a silica aerogel (n=1.0411) [7] and wavelength-shifting fibers.
- An effective area: 300×100 mm^2
- ^{40}K β rays cannot emit Cherenkov photons.
- Cosmic ray μ is suppressed at zenith angle of 0-90°.





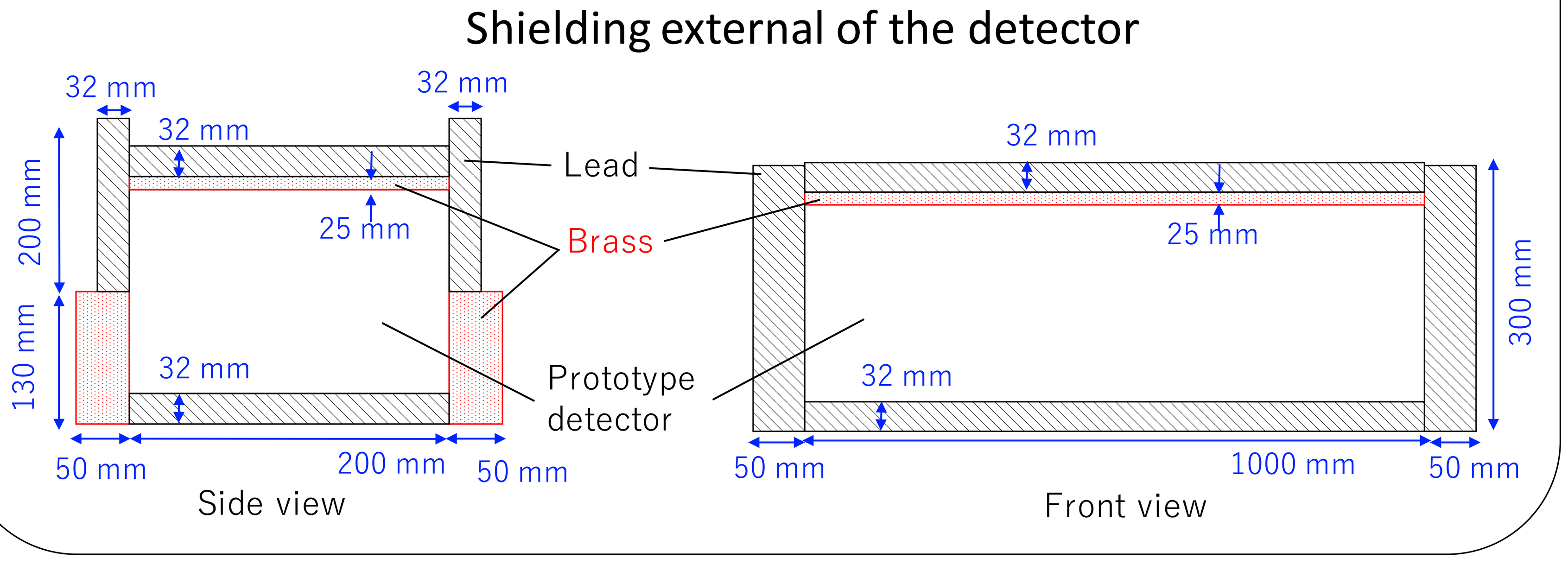
Suppressing the Background

BGO γ energy spectroscopy test



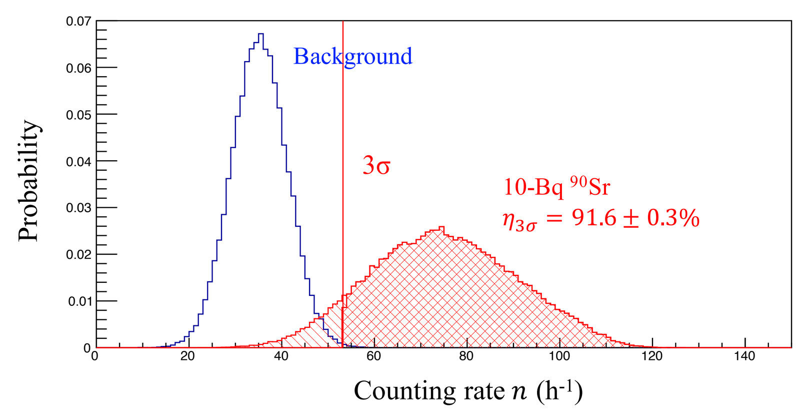
- γ rays (E>2 MeV) from ^{214}Bi, ^{40}K, ^{208}Tl in concrete of the building ceiling were observed by BGO γ energy spectra.
- The detector was shield externally by lead and brass blocks.
- By shielding external of the detector, the background rate was reduced to 35±6 h^{-1} from 125±9 h^{-1}.
- Neutral cosmic rays (γ shower of neutrons) with continuous energy cannot be suppress completely by external shielding.

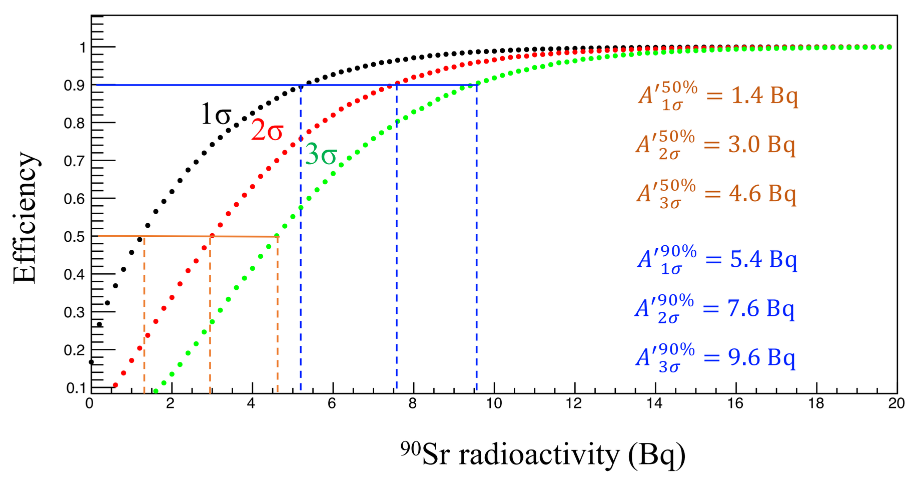
Shielding external of the detector



Result & Conclusion

The detection efficiency was estimated by the signal model. In threshold of 1, 2, and 3 σ, the efficiency curves indicate the detector performance at one hour measurement.





Source	Efficiency	Minimum Radioactivity		
		1 σ	2 σ	3 σ
^{90}Sr	50%	1.4 Bq	3.0 Bq	4.6 Bq
	90%	5.4 Bq	7.6 Bq	9.6 Bq
^{137}Cs	50%	1.3 kBq	2.5 kBq	3.8 kBq
	90%	3.1 kBq	4.5 kBq	5.8 kBq
^{40}K	50%	0.32 kBq	0.65 kBq	0.94 kBq
	90%	0.80 kBq	1.12 kBq	1.44 kBq

Lower Limit Estimation

In a case of threshold set to 3σ

- $A_{\mathrm{Sr}}^{50\%}/S = 0.0153$ Bq/cm^2 at T=1 h, S =300 cm^2
- $A_{\mathrm{Sr}}^{50\%}\varepsilon/m = 46$ Bq/kg for dried seafood sample $\varepsilon = 0.3$, $m = 30$ g T=1 h, S =300 cm^2

Conclusion

- BG was suppressed by external shielding.
- Signal model to reproduce the data was developed.
- Contamination Limit of foods is defined as 100 Bq/kg by Ministry of Health, Labour and Welfare, Japan.
- Detector performance meets the requirement.

Reference

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