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Gross beta determination in drinking water using scintillating fiber array detector

Wen-Hui Lv[a,b], Hong-Chang Yi[a], Tong-Qing Liu[a], Zhi Zeng[a,*], Jun-Li Li[a], Hui Zhang[a], Hao Ma[a]

[a] Key Laboratory of Particle and Radiation Imaging (Ministry of Education) and Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[b] Xi'an Research Institute of Hi-Tech, Xi'an 710025, China

HIGHLIGHTS

- This paper developed a scintillation fiber array detector for gross beta real-time monitoring in drinking water.
- The background counting rate is 38.131 ± 0.005 cps, and the detection efficiency is 0.37 ± 0.01 cps/(Bq/l).
- The detector can reach its detection limit of 1.0 Bq/l for beta particles within 120 min without pre-concentration.

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ABSTRACT

A scintillating fiber array detector for measuring gross beta counting is developed to monitor the real-time radioactivity in drinking water. The detector, placed in a stainless-steel tank, consists of 1096 scintillating fibers, both sides of which are connected to a photomultiplier tube. The detector parameters, including working voltage, background counting rate and stability, are tested, and the detection efficiency is calibrated using standard potassium chloride solution. Water samples are measured with the detector and the results are compared with those by evaporation method. The results show consistency with those by evaporation method. The background counting rate of the detector is 38.131 ± 0.005 cps, and the detection efficiency for β particles is 0.37 ± 0.01 cps/(Bq/l). The MDAC of this system can be less than 1.0 Bq/l for β particles in 120 min without pre-concentration.

1. Introduction

Monitoring the total radioactivity in drinking water is a counting technique to evaluate water quality. It is challenging and time-consuming to determine the concentrations of radionuclides in drinking water due to their trace concentrations. Gross alpha and beta radioactivity levels are two conventional screening indicators to evaluate the radioactivity in drinking water. It is necessary to analyze radionuclides in drinking water when gross alpha and beta radioactivity values are higher than screening levels (Todorović et al., 2012).

The screening levels for gross alpha and beta radioactivity in drinking water, mainly suggested by the World Health Organization (WHO), the European Union (EU), and the United State Environmental Protection Agency (USEPA) (WHO, 2011; European Union, 1998; Altenburger, 1989), are 0.5 Bq/l and 1.0 Bq/l, 0.1 Bq/l and 1.0 Bq/l, and 0.19 Bq/l and 0.56 Bq/l (USEPA, 2015), respectively.

Traditionally, the evaporation and co-precipitation methods are used to measure the gross alpha and beta radioactivity in drinking water, which are more suitable in lab environment. For the evaporation method, a 0.1–2 L water sample is slowly evaporated until completely concentrated. By measuring the solid residues (ISO, 9697, 2015; BS EN ISO 10704, 2015) with a proportional counter (Ibrahim et al., 2016; Fasae, 2013) or scintillator detector (Bonotto et al., 2009; Mingote et al., 2016), the gross alpha and beta radioactivity can be determined. The evaporation method has such advantages as reliable measurement results and low detection limit. However, it is time-consuming and inefficient to monitor real-time radioactivity in water, especially in the case of unexpected radioactive events (Hughes and Devol, 2003; 5750.13-2006, 2007). Compared with the evaporation method, the co-precipitation method demands more chemical treatments. The radionuclides in water chemically react with added carriers and precipitate, and the gross alpha and beta radioactivity are measured through the precipitation. Typically, radium isotopes are co-precipitated with Ba^{2+} as $Ba(Ra)SO_4$; and uranium, thorium, and polonium isotopes are co-precipitated with $Fe(OH)_3$ by adding Fe^{3+} carrier (ISO 13165, 2016; Jinxin et al., 2016). With all of the methods above, concentration takes

* Corresponding author.
E-mail address: zengzhi@tsinghua.edu.cn (Z. Zeng).

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a long time and they are not suitable for monitoring real-time radioactivity in water. In order to rapidly measure the radioactivity in drinking water and raise an alarm promptly in case of a radioactivity accident/incident, an on-line monitoring method for measuring the gross radioactivity in drinking water should be developed.

Recently, the EU is developing a tap water radioactivity real-time monitoring (TAWARA_RTM) system (Bodewits et al., 2015; Carconi et al., 2017). TAWARA_RTM system consists of 24 EJ-444 scintillation detectors, each with an area of 200 × 200 mm^2. The total active area of the detectors is 1.92 m^2. The system is designed to measure gross alpha and beta radioactivity in the order of 1.0 Bq/l in several tens of minutes. Until now, there is no reference on the experiment result of the detection limit of this system.

In this research, an on-line gross beta radioactivity monitoring system with scintillating fibers is developed, which has the advantages of no pretreatment of water samples, a simple operation process, and relatively short measurement time.

2. Framework of the system

The scintillating fiber array measurement system is composed of a detection module, an electronic module, and a data processing and acquisition module. The schematic of the detector is shown in Fig. 1.

The detection system consists of 1096 scintillating fibers, each with a diameter of 1 mm and a length of 50 cm. The distance between two scintillating fibers is about 2.5 mm. Both ends of the scintillating fibers are fastened into bundles and connected to a photomultiplier tube, and the photomultiplier tubes are sealed in polyvinyl chloride (PVC). The PVC shell is sealed to prevent water from entering. The detector is placed in a rectangular stainless-steel water tank with a volume of 160 × 80 × 80 cm^3. The electronic module contains circuits with various functions. The emitter follower circuit ensures impedance matching and isolates the signal between the divider and the output signal processing circuit. The differential circuit narrows pulse width to prevent pulse pileup. The discriminator could discriminate the noise baseline of the detector and retain the pulse amplitude. The shaping circuit adjusts the output signal into a square wave, and transmits it to a multi-channel pulse amplitude analyzer. The data processing and acquisition module receives the square wave signal and converts it into counts, and it also has the functions of adjusting the sampling time and voltage as well as providing automatic measurement and storage. The detection system measures the gross beta counting and sets the alarm threshold.

In measuring the water sample, the drinking water from tap/buckets is put into the water tank so that the scintillating fibers are in full contact with water. The radionuclides in the water deposit their energy into the fibers and generate fluorescence. The fluorescence is transmitted to both ends of the fibers by total reflection and photoelectrons are generated on the cathode of the photomultiplier tubes. After electronic circuit processing, the signals are converted to counts and recorded. The detector can measure the total counts of beta particles.

3. Performance test of the detector

3.1. Voltage test without water

The working voltage of the photomultiplier tube has a great influence on the photocurrent. The optimal voltage can be determined according to the characteristics of the plateau curve of the system in the range of 500–1100 V. 100.0 g analytical reagent potassium chloride (KCl) was packed in a thin sealed bag, and the bag was put under the scintillating fibers. The detector was shielded by lead bricks to prevent environmental radiation. The total beta count of each working voltage was measured 120 times, and each time was measured 1 min. Fig. 2 shows the average count for KCl as a function of the working voltage.

Fig. 2 shows that the plateau region was in the range of 800–1100 V. In order to reduce background noise signals and protect the photomultiplier tube, the voltage was set to 800 V.

3.2. Background test with purified water

For low-level counting devices, the background count distribution

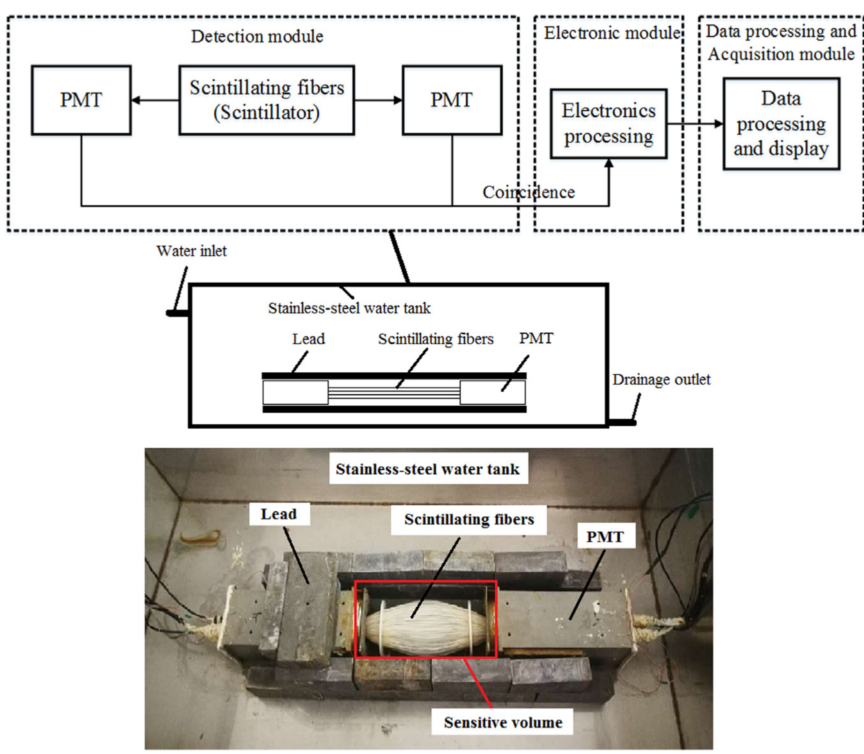

Fig. 1. Schematic of the proposed measurement system.