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A Review on the Research Status and Development Trend on Low Energy Beta-Emitter Measurement

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1. Introduction

Globally, the characterization of residual radioactivity at the decommissioning site and nuclear wastes treatment is essential and significant interest. Thus, there have been developed a number of technologies on the fabrication of detectors to measure various radioisotopes [1], [2]. Generally, in the case of beta ray emitting isotopes, it relies on Liquid Scintillation Counter (LSC), which is only available in the laboratory or indirect measurement like Scaling Factor [3], [4]. In this study, we elucidated a review on the scientific research status and development trend to have better knowledge and understanding of the beta emitter measuring equipment. Herein, researches on commercial and prototype detectors to measure low energy beta emitter are presented.

2. Methods and Results

In low energy beta radioisotopes, they usually have small atom mass and short-range. Also, they have low energy that is difficult to differentiate with noise-generating at low energy areas [5]. These characters lead to challenges in identifying the radiological data of beta emitter. Numerous trials have been made to measure low energy beta emitters, there are several detectors for beta emitter technologies are introduced.

2.1 Commercial Detectors

Commercial detectors for beta measurements have been produced in several countries, including the United States and the Netherlands, with user convenience. In the United States, Gas flow type and Dual Phosphor type of counters have been produced to measure alpha/beta emitter for various purposes. In the Netherlands, SiPM-based detectors capable of alpha/beta measurement were been produced by mixing nanomaterials with plastic scintillators.

2.1.1 Ortec

Ortec in the U.S. produced a gas flow type proportional counter or a phosphor scintillator counter (Fig. 1, 2). In the case of the Gas-flow Proportional Counter, MPC-9604 (Fig. 1B), background counts were reduced using the gas flow proportional guard detector, 4 inches lead shield, and linear low voltage supply to eliminate cosmic-ray and electrical noise. On the other hand, it has shown that dual-phosphor type counters (Fig. 2), high count rate mainly apply to health physics where fast measures, such as smear and air filters, are required.

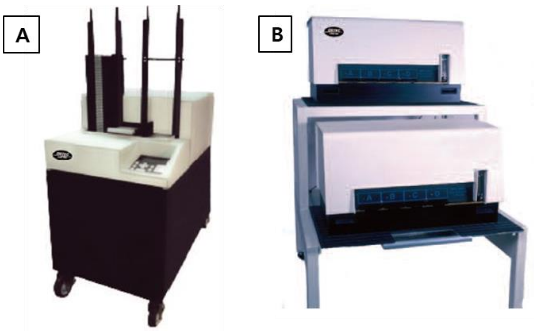

Figure 1. Gas flow type proportional counter
(A) WPC-1150-GFW [6], (B) MPC-9604 [7]

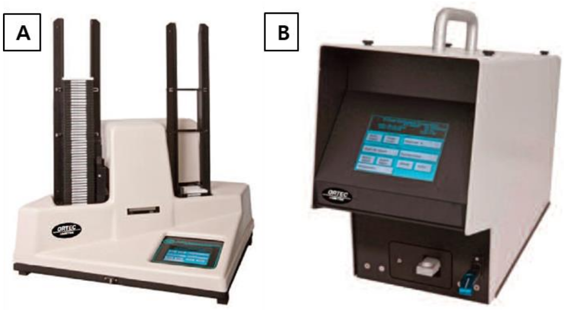

Figure 2. Dual phosphor type counter, (A) ASC-950-DP Automatic Sample Changer [6], (B) MPC-900-DP Manual Single Sample change [8]

2.1.2 Scionix

Scionix in the Netherlands produced alpha/beta detectors using SiPM as optical sensors (Fig. 3A). The detector consists of a plastic scintillator mixed with ZnS(Ag) particles and located in a stainless steel grid to block the light with a double aluminum Mylar incident window (Fig. 3B).

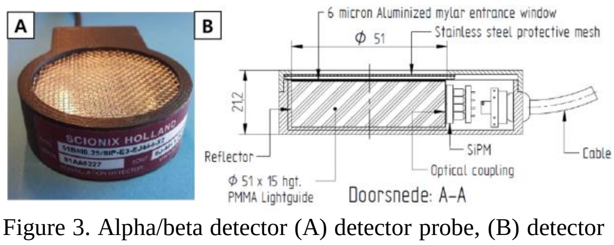

Figure 3. Alpha/beta detector (A) detector probe, (B) detector plane figure [9]

2.2 Prototype Detectors

The conventional low-energy beta emitters were measured using a Liquid Scintillator Counter due to their short range. This requires pretreatment for sampling and long analysis time [5], [10]. Besides, complex systems make it difficult to operation automatically, which is unsuitable for continuous monitoring [11]. Solid detectors can directly measure radiation, but corrosion by water leads to performance degradation over time [12]. To overcome these shortcomings, studies are being conducted on the fabrication of flow cells for tritium water monitoring at home and abroad to measure tritium in real-time. Therefore, this section looks at the trend of R&D that flow cells being understudying.

2.2.1 Flow Cell Type

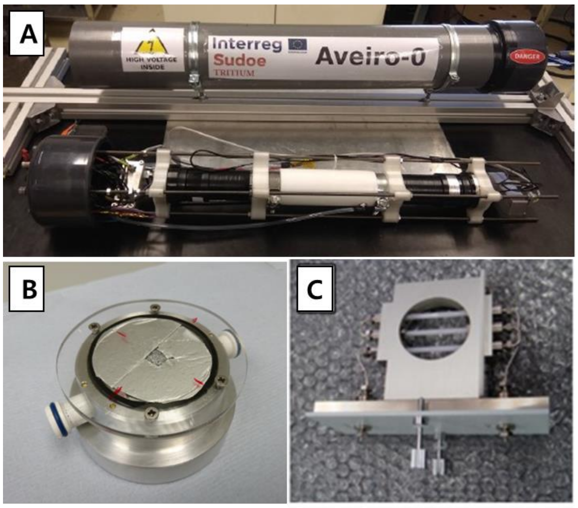

Figure 4. Flow cell type detectors understudy (A) EU [13], (B) Lancaster [12], (C) National Institute for Fusion Science [14]

2.2.1.1 Southwestern European Institution

In 2019, the EU configured a real-time system for monitoring low-level tritium flowing into rivers by installing it in the Arrocampo dam at the Alamaz Nuclear Power Plant in Spain [15]. Figure 4A represents a prototype detector, consisting of 500 optical fibers 25 cm long and 1 mm in diameter. The cladding was not included to maximize detection areas by low energy.

2.2.1.2 Lancaster University

In 2019, the University of Lancaster, England, fabricated a flow cell to monitor tritium concentrations flowing into the river. In this study, the scintillator was manufactured by depositing the Granulated CaF2: Eu particles onto the PDMS substrate using Mortar & Pestle. Aluminum blocks are machined to make flow cells and SiPM is fitted to the center of the lid (Fig. 4B).

2.2.1.3 National Institute for Fusion Science

In 2017, Japan developed a flow cell-based system to monitor leakage of tritium from the Fukushima nuclear plant accident. The flow cell detector is configured three granulated caF2 inorganic scintillators with a diameter of 5mm in the Teflon-Perfluoroalky (PFA) tube (Fig. 4C) [14], [16].

2.2.2 Digital Autoradiography

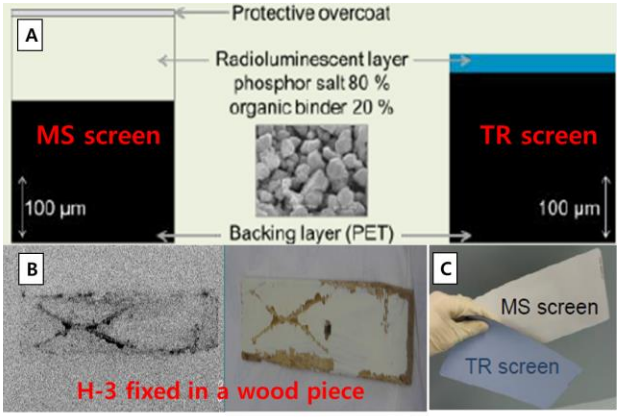

Figure 5. (A) Composition of MS/TR screen for digital autoradiography [17], (B) H-3 fixed in a wood piece [18], (C) DA screens (MS, TR screen) [17]

In 2017, the French CEA developed Digital Autoradiography (DA) to characterize radioactive wastes through quantification of residual radioactivity at decommissioned sites. The screen used in the DA is shown in Figure 5. The TR (Tritium) screen does not have a protective layer to react sensitively to tritium, while the MS (Multi Sensitive) screen has a radiation-sensitive part coated with a protective layer (Fig. 5A). Two-dimensional mapping can be obtained by placing DA screens in radiologically contaminated sites at different locations to collect radiological information.

3. Summary and Outlook

We overviewed recent research status on the trends of technologies for the low energy beta emitter measurements.

Table 1 Comparison of commercial counter in Ortec

Counter type	**Dual Phosphor type**	**WPC-1150-GFW**	**MPC-9604**
90Sr/90Y efficiency	45%	63%	55%
BKG performance	40 cpm	1.5 cpm	0.4 - 0.7 cpm
Detector diameter	2 inch	3.5 inch	32W × 16D × 16H inch

Commercial detectors have manufactured in the United States, Netherlands and other countries. The characteristics of commercial scintillators in Ortec were compared in Table 3. In the case of the dual-phosphor type counter in Ortec, it is more portable than the gas-flow type counter because it works independently with external sources except for gas connections and voltage supplies. However, the measurement efficiency for the 90Sr/90Y was 45%, lower than the gas-flow type counter.

Table 2 Comparison of Flow Cell Detector

Country	**EU**	**England**	**Japan**
Scintillator	Plastic (Epic crystal)	CaF2:Eu + PMSD substrate	Granulated CaF2
Photo Sensor	PMT	PMT	PMT
Coincidence Mode	O	×	O
MDA	0.1 Bq/mL	-	10 Bq/mL

Many studies have been conducted on the fabrication of flow cells to monitor tritium in real-time in Eu, UK, Japan, and other countries. It was compared the flow cells configured in each country in Table 2. Two PMTs were connected to the flow cell to remove PMT noise which increases the detector sensitivity. For Aveiro detectors in the EU, the use of lead shield and VETO detectors was intended to minimize the influence of external radiation and cosmic-ray. In addition, the inside of the container has optimized the reflection of light by using a Teflon wall.

In Lancaster University, England, a flow cell consisted of 12 scintillator layers to improve efficiency by increasing the surface area of water between scintillator contact. In the case of CEA, by observing radioactive contamination in a two-dimensional map, hotspot and pollution homogeneity of radioactive waste can be identified (Fig. 5B). However, only contamination by one radioisotope can be measured in a radioisotope coexisted site.

The purpose of comparing external commercial scintillators and detectors was to analyze the production status of scintillators and detectors produced for monitoring and measuring low energy beta emitting isotopes worldwide. Each approach in low-energy beta emitter measurements has a distinctly different mechanism and its advantages. To achieve the task of measuring low-energy beta-ray emitters, the system design was essential to improve detection efficiency due to beta emitter self-absorption. Also, there were attempts to monitor tritium in real-time with requiring non-corrosive probe parts and simple systems for automatic operation. These have been made Low-energy beta-emitters successfully detected, and in the case of flow cells, shown to meet the tritium concentration requirements among the edible water (EPA, U.S.: 740 Bq/L, EURATOM, EU: 100 Bq/L) in each country. However, it was deemed that the currently developed detector for measuring low-energy beta-emitters could detect only one radioisotope in an environment mixed with radiological contamination by various radioisotopes, some notable tasks remained unsolved as ever. An alternative potential approach is to develop nanocomposite to form a sensitive probe by further increasing the efficiency of scintillators that can separate energy. Once these efforts are accompanied, it is believed that we will be able to find a full field of research to approach major unresolved challenges.

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