A measurement system for alpha and beta surface emission rate using MWPC*

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Abstract: We have developed a large area multi-wire proportional counter (MWPC) as a standard for the measurement of alpha and beta surface emission rate at the Shanghai Institute of Measurement and Testing Technology (SIMT). To shorten the preparation time for chamber gas refilling, a self-designed gas control unit was adopted. Various characteristics of the system have been studied. The uncertainties were analysed. Three certified alpha plane sources (Am-241) and six certified beta plane sources (Tl-204 and Sr-90/Y-90) were measured by this system. The results show excellent agreement with the surface emission rate reported by the National Institute of Measuring, China (NIM) that E_n values of all measured sources are within ±1.

Key words: alpha/beta counting, surface emission rate, plateau curve, MWPC

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1 Introduction

Plane sources are quantified in terms of surface emission rate. Known alpha and beta plane sources are widely used as reference standard sources to calibrate surface contamination monitors, or to calibrate other reference transfer instruments [1]. The gas flow multi-wire proportional counter (MWPC) is a recommended instrument for the measurement of alpha and beta plane sources by ISO 8769[(a)]. It is possible to construct a multi-wire chamber with a large sensitive area. In addition, the source is directly introduced into the chamber, thus there is no loss of detection efficiency due to the entrance window. This is an absolute measurement system for the calibration of alpha and beta plane sources, for the MWPC has an efficiency of nearly 100% for the measurement of both alpha and beta plane sources.

This paper describes a standard measurement system for alpha and beta emission rate at the Shanghai Institute of Measurement and Testing Technology (SIMT). The multi-wire chamber is self-designed and constructed at Chengdu University of Technology. The internal structure of the multi-wire chamber is described and various characteristics have been studied. Alpha and beta operating voltage, dead time, threshold and background were determined. The newly characterized system was verified with 150 mm×100 mm certificated alpha and beta reference plane sources (Am-241, Sr-90/Y-90 and Tl-204), the surface emission rate of the alpha and beta plane sources used ranged from 10^3 min^{-1} to 10^6 min^{-1}. The results were compared to the surface emission rate reported by the National Institute of Measuring, China (NIM) and E_n values of all measured reference sources were calculated.

2 Measurement system

The system consists of a multi-wire chamber, lead chamber, charge sensitive pre-amplifier, main-amplifier, micro control unit, high voltage supply, personal computer, regulated gas supply, gas control unit and vacuum pump.

The chamber consists of aluminum, the external dimension of the multi-wire chamber is 390 mm×390 mm×70 mm, and the inner size of the chamber is 300 mm×300 mm×50 mm. The anode wires consist of tungsten, 10 μm in diameter, with 1 μm gold plating. Regardless of position resolution in this counting system and

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to have a large active sampling area, five parallel anode wires are connected together to the pre-amplifier. The anode wires are evenly spaced 45 mm from each other. Two of the outer anode wires are spaced 60 mm to the edge of the chamber frame. The cathode wires plane consists of stainless steel wires, 100 μm in diameter. The cathode wires are evenly spaced 12 mm from each other. The anode wire plane is sandwiched between a cathode wire plane and another cathode plane made of copper clad laminate, spaced 25 mm from both cathode planes. Positive high voltage is supplied in the anode wires. The multi-wire proportional counter is operated at atmospheric pressure with P-10 gas (90% Argon and 10% Methane). The sensitive area is 280 mm×280 mm. Fig. 1 shows the internal structure of the multi-wire chamber.

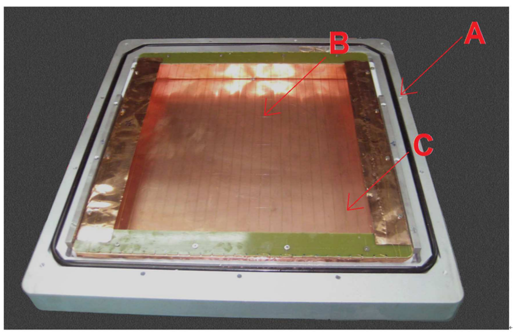

Fig. 1. (color online) Internal structure of multi-wire chamber. A, chamber; B, anode wire; C, cathode wire.

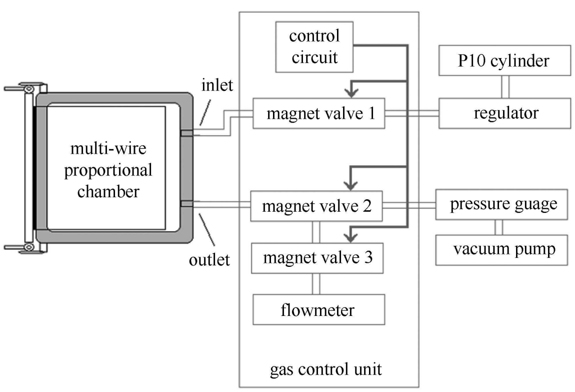

Fig. 2. Diagram of gas control unit.

Figure 2 shows the diagram of the gas control unit. The preparation time can be shortened with the gas control unit. The end of the preparation time is decided by calculating the standard deviation of continuous statistics. Preparation time is approximately 10 minutes for each measurement. Fig. 3 shows the counting rate plotted as a function of gas-filling time. The metal chamber provides a hermetic seal that allows the internal pressure to achieve a vacuum degree of more than −0.1 MPa. Besides, the chamber was connected to the ground for EMI shielding. Typical preparation procedure of the gas control unit is as follows:

1) Open magnet valve 2, close magnet valve 1 and magnet valve 3. Open the vacuum pump, depressurize the chamber until the pressure reaches −0.1 MPa.

2) Open magnet valve 1, close magnet valve 2 and magnet valve 3. Refill the chamber.

3) Open magnet valve 1 and magnet valve 3, close magnet valve 2. Turn the regulator, control operating gas flow rate at 50 ml/min.

4) Count the source until the counting rate becomes stable.

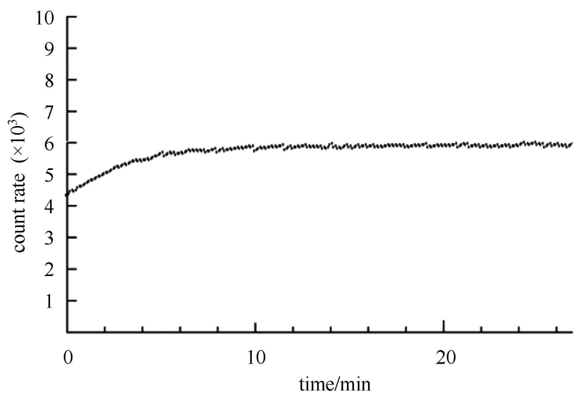

Fig. 3. Counting rate plotted as a function of gas-filling time.

3 Characterization of the measurement system

3.1 Threshold cut

The beta counting threshold should be set to a value of 0.59 keV in accordance with ISO 8769. The 5.9 keV X-ray from Fe-55 source was measured and a 512-channel multi-channel analyzer was used to obtain the spectrum. The threshold is just above 0.1× the energy of Fe-55 X-ray. Fig. 4 shows the Fe-55 spectrum. For alpha counting the threshold was set just above the electronic noise [2].

3.2 Plateau curve

The alpha and beta plateau curves are plotted by measuring the Am-214 source and Sr-90/Y-90 source and are shown in Fig. 5 and Fig. 6. The length of the alpha plateau is about 500 V, the length of the beta plateau is about 400 V. The slope of the alpha plateau is 0.5%/100 V, the slope of the beta plateau is 2.8%/100 V. Long and flat plateaus indicate that the detector is in perfect condition. The operating voltages were chosen in the middle of the plateau to minimize the sensitivity

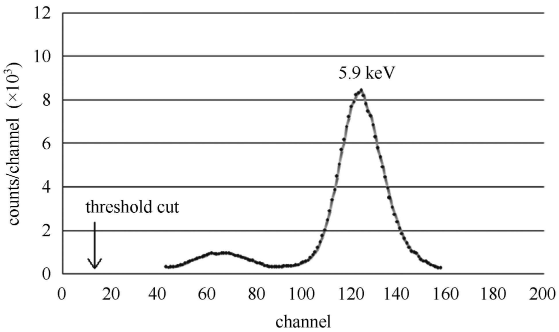

Fig. 4. Fe-55 spectrum.

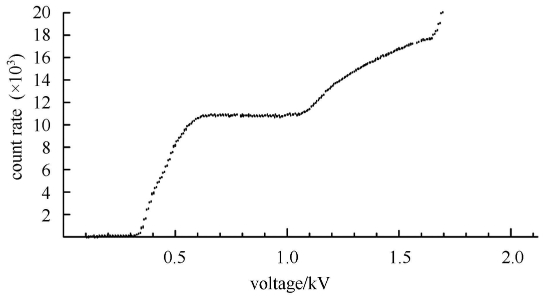

Fig. 5. Alpha plateau curve by measuring Am-241.

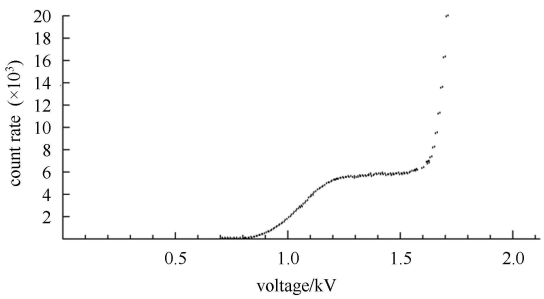

Fig. 6. Beta plateau curve by measuring Sr-90/Y-90.

of the measurement system to small voltage drifts [2]. The alpha and beta operating voltages were 800 V and 1400 V respectively.

3.3 Background

In order to minimize the background, the multi-wire chamber was put in a lead chamber with a wall thickness of 25 mm. The alpha background was 5.3 counts/min^{-1} on average, the beta background was 1508.3 counts/min^{-1} on average. The background counting rate of an alpha measurement is very low, these counts are mainly from the multi-wire chamber's wall material or contamination on the surface. However, the background counting rate of beta measurement is mainly from environmental gamma-rays and cosmic rays.

3.4 Stability

As a reference transfer instrument for alpha and beta surface emission rate, excellent stability is required. A Sr-90/Y-90 source was measured in the same way under the same condition for 48 hours. By summing the counts over time, the source counting rates were found to be 16015.1±16.2 counts/s, which means the relative standard deviation is 0.1%. Fig. 7 shows the counting stability of the Sr-90/Y-90 source.

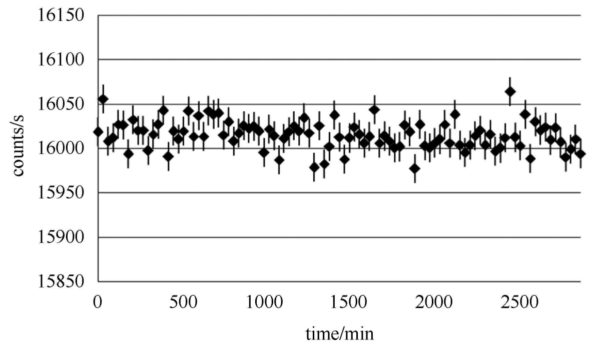

Fig. 7. Variations of the counting rates in 48 h.

3.5 Dead time

The non-extendable dead time of the electronics system was measured using the double-source method recommended by NCRP 58 [3]. Counting rate n_1, n_2 and n_{12} was obtained by measuring two sources (1) and (2) in the sequence of (1), (2) and (1+2), with the background counting rate $n_{\rm b}$. The dead time τ is given by

$$\tau=\frac{n_1+n_2-n_{12}-n_b}{2(n_1-n_{\rm b})(n_2-n_{\rm b})}. \tag{1}$$

The radionuclides for alpha/beta-emitting sources recommended by ISO 8769 have a relatively long half-life [2], so the influence of decay can be ignored. The corrected surface emission rate N is given by

$$N=f\left(\frac{n}{1-n\tau}-n_{\rm b}\right), \tag{2}$$

where N is the surface emission rate (s^{-1}), n is the system counting rate (count per second), τ is dead time (s), $n_{\rm b}$ is the background counting rate (count per second), and f represents a correction factor due to fluctuations of discrimination level settings, applied anode voltage, ambient conditions, gas purity and gas pressure. Under normal conditions of counter operation, f has small fluctuations and its expected value is equal to unity ($f=1$).

4 Results

The uncertainties of three alpha and beta 100 mm× 150 mm certificated plane sources (Am-241, Sr-90/Y-90 and Tl-204) were evaluated as examples. The summary is given in Table 1. Uncertainty was evaluated by following the Guide to the Expression of Uncertainty in Measurement [4, 5]. From Eq. (2), the combined variance $u_{\rm c}(N)$ is given by

Table 1. Uncertainty evaluations of three plane sources (Am-241, a Tl-204 and a Sr-90/Y-90).

	standard uncertainties (%)					
	Am-241		Tl-204		Sr-90/Y-90	
	type A	type B	type A	type B	type A	type B
statistics repeatability	0.32		0.45		0.35	
dead time[b]	0.003		0.005		0.005	
background[a]	0.00		0.04		0.04	
high voltage		0.03		0.02		0.02
threshold setting		0.53		0.55		0.55
total	0.32	0.53	0.45	0.55	0.35	0.55
combined uncertainty	0.62		0.71		0.65	
relative expanded uncertainty (k=2)	1.2		1.4		1.3	

a Dead time is 6.8 μs, Am-241 counting rate: 1046.6 s^{-1}, Tl-204 counting rate: 1900.0 s^{-1}, Sr-90/Y-90 counting rate: 1755.0 s^{-1}.
b Alpha background counting rate: 0.1 s^{-1}, beta background counting rate: 25.1 s^{-1}.

Table 2. Measurement results of alpha plane sources.

source	reported emission rate/s^{-1}	emission rate/s^{-1}	E_n
Am-241	114.0 (±2.5%)	112.5 (±2.8%)	0.35
Am-241	1046.6 (±2.5%)	1053.1 (±1.2%)	−0.22
Am-241	3829.4 (±2.5%)	3804.6 (±1.1%)	0.24

$$u_c^2(N) = \sum_{i=1}^{3}\left(\frac{\partial N}{\partial x_i}\right)^2 u_i^2(x_i) = \left(\frac{\partial N}{\partial x_1}\right)^2 u_1^2(x_1) + \left(\frac{\partial N}{\partial x_2}\right)^2 u_2^2(x_2) + \left(\frac{\partial N}{\partial x_3}\right)^2 u_3^2(x_3) + \left(\frac{\partial N}{\partial x_4}\right)^2 u_4^2(x_4), \tag{3}$$

where $x_1 = n$, $x_2 = \tau$, $x_3 = n_b$ and $x_4 = f$.

All of these results were corrected using Eq. (2). The results measured in SIMT were compared to the primary standard at NIM. E_n was used to evaluate this comparison[(b)]. E_n is given by

$$E_n = (X_{NIM} - X_{SIMT})/\sqrt{U_{NIM}^2 + U_{SIMT}^2}, \tag{4}$$

where X_{NIM} is the result reported by NIM, X_{SIMT} is the result measured by SIMT, U_{NIM} is the relative expanded uncertainty ($k = 2$) in X_{NIM}, U_{SIMT} is the relative expanded uncertainty (k=2) in X_{SIMT}. Table 2 shows the measurement results of three alpha plane sources (Am-241), Table 3 shows the measurement results of six beta plane sources (Tl-204 and Sr-90/Y-90). All E_n values are less than one.

Table 3. Measurement results of beta plane sources.

source	reported emission rate/s^{-1}	emission rate/s^{-1}	E_n
Tl-204	39.0 (±2.5%)	39.2 (±1.9%)	−0.16
Tl-204	250.0 (±2.5%)	245.8 (±1.6%)	0.57
Tl-204	1900.0 (±2.5%)	1883.4 (±1.4%)	0.31
Sr-90/Y-90	323.3 (±2.5%)	324.6 (±1.9%)	−0.13
Sr-90/Y-90	1755.0 (±2.5%)	1729.8 (±1.2%)	0.52
Sr-90/Y-90	17216.7 (±2.5%)	17194.7 (±1.1%)	0.47

5 Conclusion

A multi-wire proportional counter has been developed at SIMT. The system's characteristics were studied. The length of alpha and beta plateau curves is 500 V and 400 V respectively. The operating voltage of alpha and beta counting is 800 V and 1400 V respectively. Preparation time of the system is about 10 min. Dead time is 6.8 μs. The relative standard deviation of 48 h stability test is 0.1%. The alpha and beta background are 5.3 min^{-1} and 1508.3 min^{-1} respectively.

Three certificated alpha plane sources (Am-241) and six certificated beta plane sources (Tl-204 and Sr-90/Y-90) were measured and the results show excellent agreement with the results reported by NIM, which is the national standard, that the E_n values of all measured sources are within ±1. These results indicate this measurement system is capable of serving as a standard of measurement for the alpha and beta surface emission rate.

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