CPC(HEP & NP), 2012, **36**(5): 434–437 Chinese Physics C Vol. 36, No. 5, May, 2012

A boron-lined proportional counter (BLPC) used in a mixed field of reactors

CHEN Guo-Yun(陈国云)[1,2;1)] WEI Zhi-Yong(魏志勇)[1;2)] XIN Yong(辛勇)[2]
LEI Sheng-Jie(雷升杰)[1] HUANG Fu-Cheng(黄福成)[2] HUANG San-Bo(黄三玻)[1]
ZHU Li(朱立)[1] ZHAO Jing-Wu(赵经武)[3] MA Jia-Yi(马加一)[3]

[1] Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China
[2] Department of Physics, Nanchang University, Nanchang 330031, China
[3] College of Physics, Nanjing University, Nanjing 210093, China

Abstract: A boron-lined proportional counter (BLPC) with a count rate limit close to the multi-wire proportional counter was manufactured to measure the mixed field around reactors. After measurement with a standard Am-Be neutron source (activity: 100 mCi), the results show that the operating voltage of the BLPC is 800 V, the plateau length is 100 V and the slope is 13.2%/100 V. The width and rise time of the output pulse of the BLPC are 1.26 μs and 370 ns, respectively. When the BLPC works at a count rate of 1.0×10^5 count/s, the pulse pile-up probability of the BLPC is 3.6%. A clear peak can be seen in the pulse height spectrum of the BLPC. and the performances illustrate that a BLPC working in pulse mode can serve as a source range detector of reactors.

Key words: BLPC, mixed field, count rate, plateau curve

PACS: 29.40.Cs, 29.85.Fj **DOI:** 10.1088/1674-1137/36/5/009

1 Introduction

Neutrons and inevitably gamma rays usually exist around reactors, which form the mixed field neutron and photon environment. The dose rate of the mixed field varies drastically from extremely low to very high values, e.g. the neutron flux of the Qinshan nuclear plant covers 12 orders of magnitude (10^{-1}–10^{11} n·cm^{-2}·s^{-1}). The detectors used for the accurate monitoring of the mixed field are usually designed for three regions: the source range (10^{-1}–10^{5} n·cm^{-2}·s^{-1}), the middle range (10^{3}–10^{11} n·cm^{-2}·s^{-1}) and the power range (10^{9}–10^{11} n·cm^{-2}·s^{-1}) [1–3]. BF_3 counters can be used to monitor the mixed field, but their signal will be distorted because of the high temperature around the reactors. Furthermore, BF_3 is an electronegative gas, which leads to low detection efficiency [4]. Recently, boron-lined proportional counters (BLPCs) have been widely used due to their good gamma discrimination and rather long lifetime, without suffering from any deterioration of their counting and spectrometric characteristics [5].

Many studies about the measurement of the mixed field around reactors have been performed since the gas-filled proton-recoil spectrometers were first applied in 1974 [6]. One year later, Semper's gas-flow multi-wire proportional counter (MWPC) was found to have a high count rate limit of up to 10^6 count/s in the 14.4 keV energy region [7], while that of Zdzisław's MWPC is 1.5×10^6 count/s in the energy range 3–15 keV [8]. In 1980, Bednarek found that multi-cell counters can operate at a count rate one order of magnitude higher than conventional single-anode counters [9]. Then Beddingfield found that the ^{10}B lined design in ^{3}He proportional counters (PCs) will offer superior performance in the mixed field [10]. Since Jan Sernicki analyzed large-area transmission PCs filled with organic vapors in 1988 [11], the plateau characteristics of many PCs have been measured, such as Dighe's silver-lined PC (20%/10 V) [12] and Lee's windowless MWPC

Received 11 April 2011
1) E-mail: cgy8008@nuaa.edu.cn; chenguoyun@ncu.edu.cn
2) E-mail: wzy_msc@nuaa.edu.cn

(300 V, 1.4%/100 V) [13]. The properties of more PCs are presented in Refs. [14–23].

This work presents a single-wire BLPC manufactured by our laboratory, which has a high count rate limit and is especially for measuring the mixed field around reactors. By using a standard Am-Be neutron source, the high voltage plateau curve, output pulse and pulse height spectrum of the BLPC have been measured. From the experimental results, the performance parameters (such as plateau characteristics and count rate limit) and the working parameters (such as working voltage and pulse pile-up probability) of the BLPC were obtained. With the determined working parameters, the pulse height spectra of the Am-Be source have been measured, in which a clear peak appears. Finally, by comparing with the present BLPCs, the experimental results of the BLPC have been evaluated, and methods to improve the pulse height spectra are also proposed.

2 The structure of the BLPC

The detailed internal structure of the BLPC manufactured at our laboratory is shown in Fig. 1.

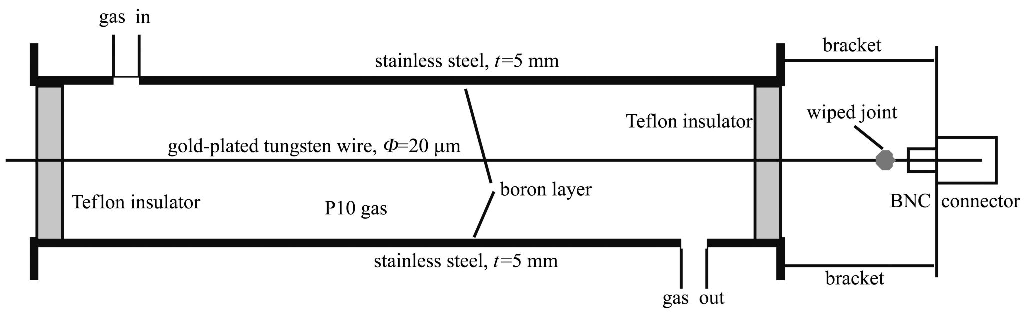

Fig. 1. The internal structure of the BLPC.

A 230 mm long precision stainless steel tube with an inner diameter of 20 mm and a wall thickness of 5 mm acts as the cathode of the BLPC. A gold-plated tungsten wire 20 μm in diameter (acting as the anode), imported from Goodfellow Cambridge Co Ltd in the UK, is accurately located in the center of the cathode. The BLPC is filled with P10 gas, produced by Shanghai Wetry Criterion Gas Co Ltd in China, at a pressure of 0.4 atm, and a flux of 10 mL/min is used to freshen the gas. A BNC connector on the right of the BLPC stands for output signal extraction. Two Teflon circular boards of 8 mm in thickness act as the insulators, with the epoxide resin used to seal the P10 gas in the BLPC. Enriched ^{10}B powder with an enrichment of 90% ^{10}B, produced in Dalian, China, is coated on the inner wall of the PC, and the thickness of the boron film is 0.5 mg/cm^2.

3 Irradiation and measurement

The neutron source used in the measurement is a standard Am-Be neutron source supplied by the Nuclear Radiation Laboratory of Nanjing University. The activity of the Am-Be source is 100 mCi and the average energy of neutrons is 4.2–5 MeV. In order to increase the detection efficiency, neutrons are slowed down by a cylindrical paraffin moderator with an outside diameter of 40 cm and a height of 25 cm. There is a hole 6 cm in diameter in the center of the moderator. The Am-Be source is located at the bottom of the hole, and the BLPC is placed on the moderator so that its active volume can be exposed to the source.

The processing modules of the pulse height analysis system of the BLPC consist of the voltage sensitive preamplifier, the linear amplifier, the precision pulse generator, the multi-channel analyzer and the digital storage oscilloscope. Apart from the oscilloscope, all the modules are supplied by Beijing Nuclear Instrument Factory (BNIF) in China. After the modules are collected, the high voltage plateau curve, output pulse, and the pulse height spectrum are shown below.

4 Results and discussion

4.1 The high voltage plateau curve

The anode radius of the BLPC manufactured in our laboratory is 20 μm and the cathode radius is 2 cm. In order to find the working point the high voltage was varied from 600 to 900 V with a step of 20 V, while the other conditions remained constant. At each voltage, the measurement lasted for 100 s. The graph between the count rates (of the full spectrum) vs. the high voltages is shown in Fig. 2.

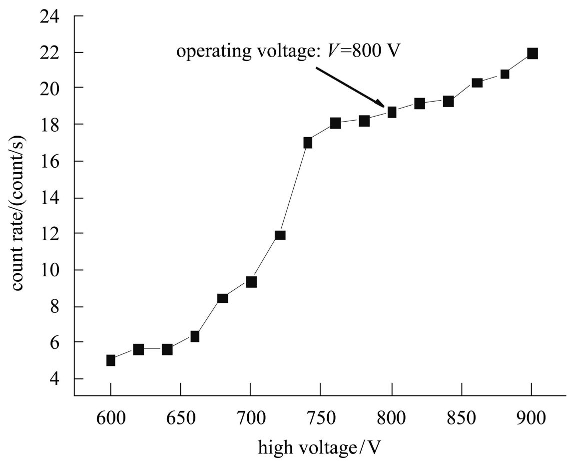

Fig. 2. The high voltage counting curve of the BLPC.

From Fig. 2 we can see that the plateau length of this BLPC is about 100 V, and the plateau slope is deduced to be 13.2%/100 V. The operating voltage of the BLPC should be 800 V. Compared with the BLPCs presented in recent years, the plateau parameters of our BLPC are better than Dighe's BLPC filled with Ar+CO_2 (5%) at 20 cmHg (100 V, 2.8%/10 V) [19], and are close to Kyriakos's BLPC filled with ^{3}He (100 V, 8%/100 V) [23].

4.2 The output pulse

The pulse waveforms recorded by the oscilloscope at a high voltage of 800 V are shown in Fig. 3.

From Fig. 3 we can see that the full width and the rise time of the pulse are t_W=1.26 μs and t_R=370 ns, respectively, which leads to a fall time of t_F=890 ns. Here we suppose that two pulses can be discriminated if a pulse comes after the rise time of the previous pulse. Without considering the resolution of the amplifier and computer, the resolution time of the BLPC can be considered as t_R. According to Ref. [24], if the detector has an average count rate of n, the probability for N pulses to appear during a time interval Δt can be given by

$$p(N,\Delta t)=\frac{(n\cdot\Delta t)^N}{N!}\exp(-n\cdot\Delta t). \qquad (1)$$

We substitute Δt =370 ns and the count rate n=1.0×10^5 count/s in Eq. (1), then no pulse appears (N=0) in the duration of 370 ns after the fore pulse should be 96.4%. That is to say, when the count rate is 1.0×10^5 count/s, the pulse pile-up probability of the BLPC is 3.6%. Since most of the amplifiers have a pile-up rejecter and baseline restorer in their shaping circuit, such as an ORTEC 572 A amplifier, the pulse pile-up probability of the BLPC would be further reduced. All these indicate that our BLPC can be used as a source range detector to measure the mixed field around reactors.

4.3 The pulse height spectrum

The pulse height spectrum of the Am-Be source measured for 100 s at a high voltage of 800 V is shown in Fig. 4.

A clear peak appears near 300 channels in the pulse height spectrum (Fig. 4), but the counts are rather low (less than 50 counts near the 300 channel). The first reason that leads to a low count rate may be that (1) the collimating hole is too small, so only a few neutrons exit from the moderator. As we know, the neutron reaction cross section is in proportion to the inverse of its velocity in the low energy region, thus the second reason would be that the energy of the incident neutrons is too high (several MeVs), and the cross section of the neutrons is small, which results in a low count rate. To improve the count rate of the BLPC, we are designing a cylindrical Bonner sphere system (BSS), which is used to wrap the BLPC during the measuring process. Since the BSS material can slow down neutrons, which would increase the cross section of the reactions, the detection efficiency and the count rate would be improved accordingly. Further results in this field will be presented soon.

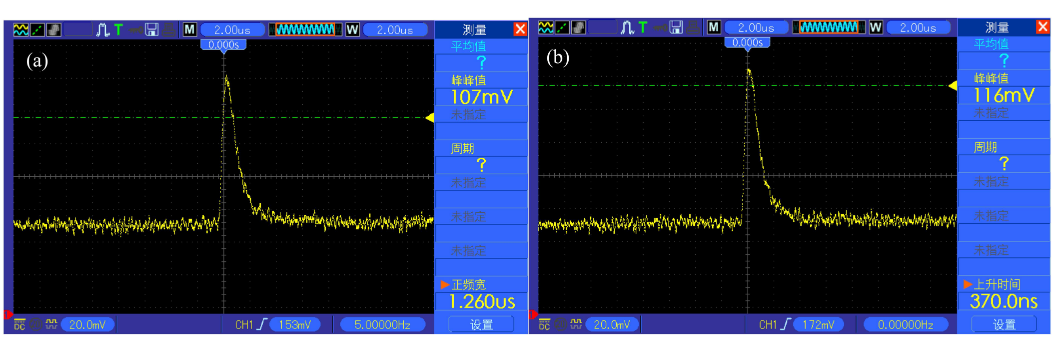

Fig. 3. (color online) The output pulse of the BLPC. (a) and (b) are recorded continuously, and different pulse parameters were measured.

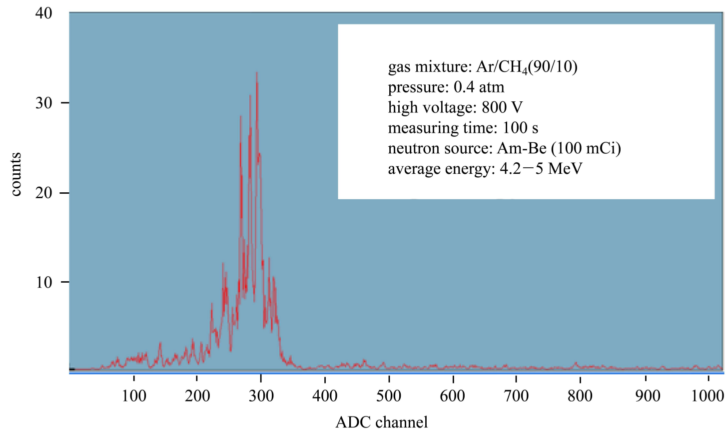

Fig. 4. (color online) The pulse height spectrum of the Am-Be source.

5 Conclusions

A BLPC with a count rate limit close to that of MWPC has been manufactured, and the detailed internal structure is shown in this work. By using a standard Am-Be neutron source with an activity of 100 mCi, the high voltage plateau curve, the output pulse, and the pulse height spectrum of the BLPC are measured.

From the high voltage plateau curve, the operating voltage of the BLPC is determined to be 800 V. The plateau length of the BLPC is 100 V, and the plateau slope is 13.2%/100 V. These features exceed Dighe's BLPC filled with Ar+CO_2 (5%) (100 V, 2.8%/10 V) [19], and are close to Kyriakos's BLPC filled with ^{3}He (100 V, 8%/100 V) [23].

The amplitude of the output pulse of the BLPC is about 100 mV, and the width and rise time are 1.26 μs and 370 ns, respectively. When the BLPC works at a count rate of 1.0×10^5 count/s, the pile-up probability of the pulse is 3.6%. The BLPC working in pulse mode can serve as a source range detector to monitor the mixed field neutron and photon environment around reactors.

A peak appears in the pulse height spectrum of the BLPC, but the count rate is rather low. A cylindrical Bonner sphere system (BSS) is being designed to slow down the neutrons, which would greatly improve the count rate of the BLPC.

References

1 LIU Jiong, ZHANG Fan, ZHANG Rui et al. Nucl. Power Eng., 2003, **24**(1): 231 (in Chinese)
2 ZHANG Jian-Ming, Olmstead R A. Nucl. Power Eng., 1999, **20**(6): 507 (in Chinese)
3 WANG Zhi-Guo, YUE Sheng. Nucl. Power Eng., 2002, **23**(6): 24 (in Chinese)
4 Dauphin G, Duchene J. Duchene. Long Life Boron-Lined Proportional Counters Fitted to the Start-Up Range of the Nuclear Reactors. In French Atomic Energy Commission Technical Report CEA-N-2299. Gif-Sur-Ivetter, France: CEA Centre d'Etudes Nucleuires de Saclay, 1983, 28
5 Mazed D. Radiat. Meas., 2007, **42**: 245
6 Victor V V, Raffaele G. Nucl. Instrum. Methods, 1974, **114**(2): 205
7 Robert J S, Guarnieri C R, Walker J C. Nucl. Instrum. Methods, 1975, **129**(2): 447
8 Zdzisław P, Wojciech C. Nucl. Instrum. Methods, 1978, **157**(2): 287
9 Bogusław B. Nucl. Instrum. Methods, 1980, **175**(2–3): 431–439
10 Beddingfield D H, Menlove H O, Johnson N H. Nucl. Instrum. Methods A, 1999, **422**: 35
11 Sernicki J. Nucl. Instrum. Methods A, 1988, **270**(1): 200
12 Dighe P M, Prasad K R, Kataria S K. Nucl. Instrum. Methods A, 2004, **523**: 158
13 Lee K B, Lee J M, Park T S. Appl. Radiat. Isot., 2005, **63**: 99
14 Curzio G, Mazed D, Ciolini R et al. Nucl. Instrum. Methods A, 2005, **537**: 672
15 XIE Feng, CHANG Yong-Fu, LU Jia-Chun et al. Nucl. Elec. & Detect. Tech., 2005, **25**(2): 204 (in Chinese)
16 LI Qi, CHANG Yong-Fu, XIE Feng et al. Atom. Energy Sci. & Tech., 2006, **40**(4): 443 (in Chinese)
17 Desai S S, Shaikh A M, Nucl. Instrum. Methods A, 2006, **557**: 607–614
18 Deptuch M, Kowalski T Z, Mindur B. Nucl. Phys. B, 2006, **150**: 394
19 Dighe P M. Nucl. Instrum. Methods A, 2007, **575**: 461
20 REN Yi, MENG Dan, DENG Chang-Ming et al. Nucl. Elec. & Detect. Tech., 2007, **27**(4): 756 (in Chinese)
21 George A K. Appl. Radiat. Isot., 2008, **66**: 860
22 WANG Zhi-Gang, DENG Chang-Ming, ZHANG Shi-Rang. Nucl. Elec. & Detect. Tech., 2010, **30**(8): 1105 (in Chinese)
23 Kyriakos T, Robert D M. Nucl. Instrum. Methods A, (article in press)
24 WANG Jing-Jing, FAN Tian-Ming, QIAN Yong-Kong. Nuclear Electronics, Beijing: Atomic Energy Press, 1983, 50–52 (in Chinese)