CHAPTER 45

Comparison of Various Anticoincident Shields in Liquid Scintillation Counters

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ABSTRACT

In low level liquid scintillation counters, most of the background can be eliminated by an anticoincident detector. NaI(Tl) crystal is well-known as an effective shielding detector in gamma ray spectrometers or in liquid scintillation counters. The plastic scintillator and liquid scintillator have also been used in commercial instruments, but all of these detectors are large and expensive. Four types of anticoincident detector have been tested in our laboratory.

As a result of the experiments, G-M tubes, made of stainless steel or glass, are very effective in reducing the background from cosmic rays, in particular for ^{14}C. Background in ^{14}C measuring channel is lower than 1 cpm, with the efficiency over 75% for 5 mL benzene samples. So, G-M tubes provide a cheap, compact, and effective anticoincident shield.

Bismuth germanate(BGO) crystal, in pieces as an anticoincident detector, is only about 2 kg. The effect is as well as NaI(Tl) crystal which weighs about 14 kg. Furthermore, different from NaI(Tl), BGO is not hygroscopic and damagable.

The effect of the plastic scintillator as an anticoincident detector is between the effect of solid crystals and G-M tubes.

The background spectrum for all four types of detector and the analysis are given and analyzed.

INTRODUCTION

As is known, an anticoincident shielding can effectively decrease the background of the main detector. J. E. Noakes[1] first introduced NaI(Tl) crystal as an anticoincident shielding detector (AD) to the low background liquid scintillation counter. Then plastic scintillator and liquid scintillation solution were introduced to the liquid scintillation counter and good results have been obtained. Since the '80s, counting tubes and multiwire proportional counters have been tested,[2-4] but people have not got the anticipated results. Therefore low background liquid scintillation counters are always associated with being large, heavy, and expensive.

A lot of experiments about various AD for liquid scintillation counters have been completed in our laboratory during the past few years. They are NaI(Tl) crystal, plastic scintillator, bismuth germanate(BGO), and common or special G-M counter. From the results, we can see that even when the common G-M counter is used as an AD, better results can be obtained. G-M counting tubes provide the cheapest AD. The γ ray efficiency of BGO crystal is higher than NaI(Tl) crystal, so a better result can be expected.

INSTRUMENT AND METHOD

Installations and Instruments of Liquid Scintillation Counters with AD

1. First, thirty-two MC-6 G-M counting tubes surrounding the main detector are arranged as a rectangle (Figure 1a). The matter shielding is 5-cm-thick lead. Second, an annular multiwire G-M halogen counting tube (Figure 1b) is specially designed (technology and manufacture completed by Beijing Nuclear Instrument Factory). Different from common commercial counting tubes, the shell is made of stainless steel. Because the product rate is too low and the cost is too much, it will not be used in commercial, low background liquid scintillation counters. The matter shielding is 5- or 10-cm-thick lead. Third, a kind of stainless steel cylindrical G-M counting tube is manufactured with shape and function similar to the common G-M γ counting tube. Fifteen counting tubes are arranged between two metal cylinders. The main detector is surrounded by the inner cylinder; the outer cylinder is surrounded by 10-cm-thick lead (Figure 1c). Fourth, the main detector is in 5-cm-thick lead annular and encircled by twenty-six common commercial glass counting tubes. Another 5-cm-thick lead annular encircles it (Figure 1d). The glass is replaced by stainless steel in order to study the effect of ^{40}K in glass on the background.
2. The anticoincident annular of plastic scintillator consists of seven detectors. Each of them includes a ϕ 76 $\times$ 150 mm plastic scintillator cylinder and a GDB-52 PMT. The distance between the center of each detector and the main detector is 105 mm. The seven detectors are arranged in various types as shown in Figure 2. The anticoincident effect of various arrangements are studied. In some experiments, only a few of the seven plastic scintillator detectors are operated.
3. The NaI(Tl) crystal annular (200 mm OD, 80 mm I.D., and 150 mm in length) is not purified for potassium. Six GDB-52 PMTs are used for collecting the photons from the NaI(Tl) crystal. This NaI(Tl) crystal is used in a DYS-1[5] low-level liquid scintillation counter.
4. The BGO AD consists of several pieces of BGO and a pair of GDB-52L PMTs. The weight of the crystals is about 2 kg. A 100 $\times$ 100 $\times$ 100 mm cubic case is made to contain these crystals. There is a ϕ 60 mm hollow in the middle of the case for placing the main detector. Please note that 2, 3, and 4 all have a 10-cm-thick lead shielding.

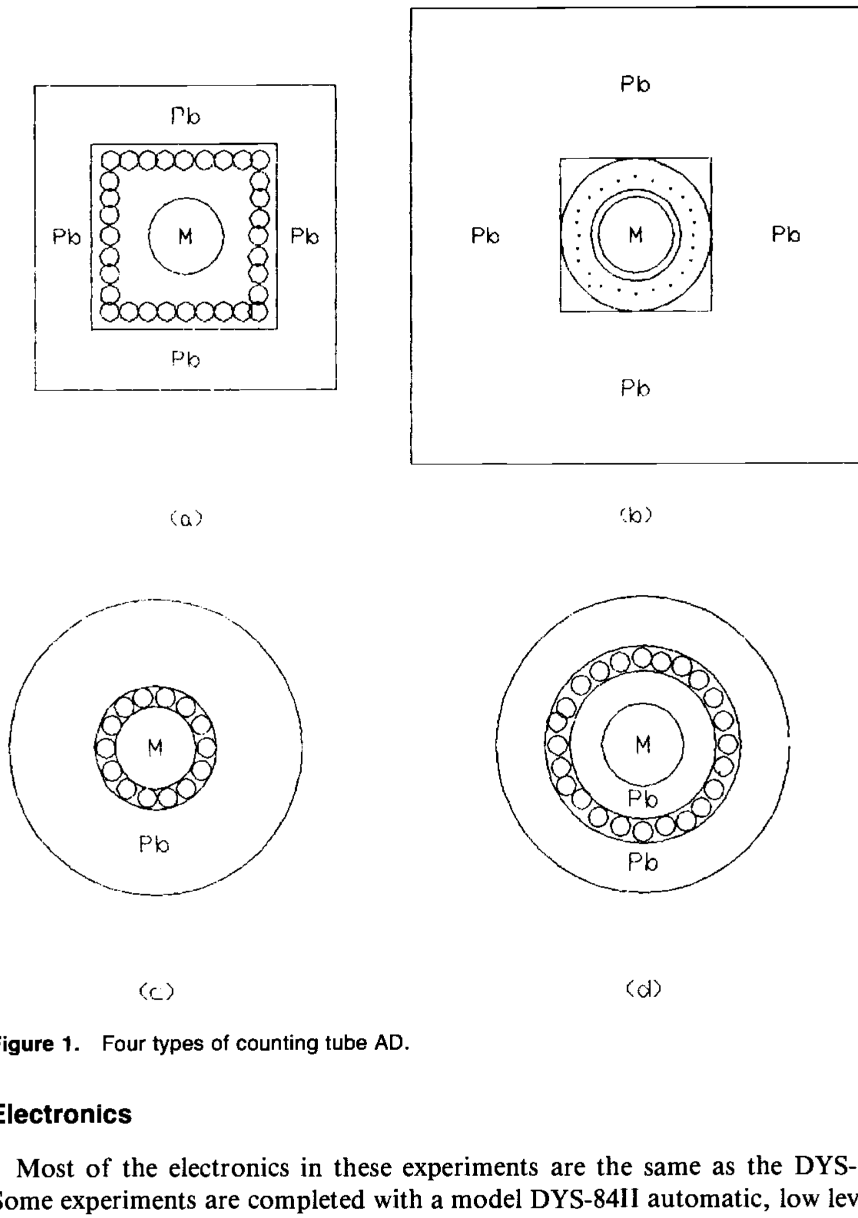

Figure 1. Four types of counting tube AD.

Electronics

Most of the electronics in these experiments are the same as the DYS-1. Some experiments are completed with a model DYS-84II automatic, low level liquid scintillation counter which has a capacity of twenty-four samples, is controlled by a Zijin II microcomputer, and has a software multichannel analyzer.

Standard Sample and Blank Sample

All of these samples are contained in quartz vials. The OD of the vial is about 27.5 mm. Different height vials are made for different volumes of samples. The

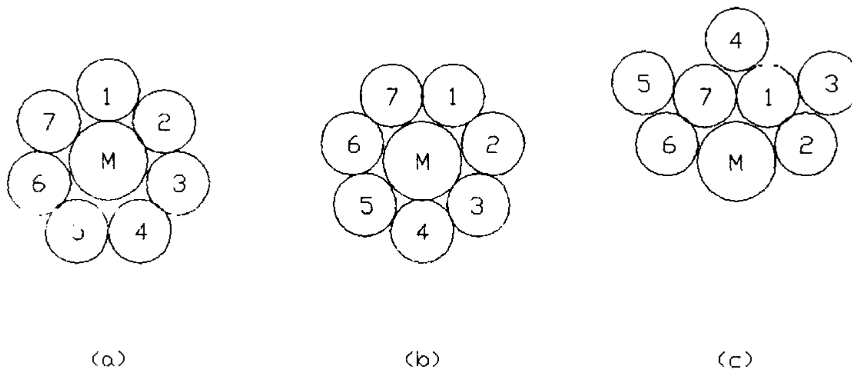

Figure 2. The arrangement of plastic scintillator detectors.

5 mL ^{14}C sample contains 5 mL benzene and 30 mg B-PBD. The 10 mL and 20 mL tritium water samples contain 60% emulsion scintillation solution (7 g PPO + 0.5 g POPOP/l toluene:triton X - 100 = 2:1) and 40% water. 20 mL tritium standard contains 20 mL benzene and 0.1 g PPO + 0.001 g POPOP. Standard samples are made up by standard solution. Blank samples are free from the radioactivity.

Main detector

The main detector consists of two EMI 9635QB PMTs and a type DYS sample chamber which can hold a 5 to 20 mL sample vial. The PMT is selected from many PMTs. Unfortunately, all of these experiments do not use the same pair of PMTs. E. Experimental condition

Experimental Condition

Counts per minute in total energy channel were measured for 20 mL benzene sample, in the operation points for 20 mL ^3H benzene sample, 10 mL tritium water sample, and 5 mL ^{14}C sample. When the AD operates, the counting rate of blank samples is abbreviated as AB. If the AD does not operate, the counting rate of blank samples is abbreviated as CB. The energy spectra of 20 mL blank and standard samples are measured. When there is no sample in the sample chamber, the measured cpm is named as EAC and ECC separately, corresponding to operation or non operation of AD.

RESULTS

Table 1 shows the results from G-M counting tube as AD in various types and conditions. It is shown that whatever the G-M counting tube is, commercial or specially made, all of them can effectively decrease the background, particularly for the ^{14}C channel. For 5 mL ^{14}C sample, when the efficiency is

Table 1. The Effect of AD of Counting Tubes

1a

The type of AD	Operating State: No E (%)	No B (cpm)	No E^2/B	Yes E (%)	Yes B (cpm)	Yes E^2/B	A.E. (1)
Annular tube	77.0	3.81 ± 0.06	1560	76.8	1.32 ± 0.03	4470	65%
32 MC-6 tube	81.9	4.15 ± 0.16	1616	81.1	2.02 ± 0.04	3260	51%

Note: 5 cm-thick lead

1b

Type	5 mL ^{14}C Operating State: No E (%)	No B (cpm)	No E^2/B	Yes E (%)	Yes B (cpm)	Yes E^2/B
Figure 1(d)	76.5	3.42 ± 0.18	1711	76.5	0.88 ± 0.09	6650
Figure 1(c)	76.7	2.91 ± 0.05	2022	76.7	0.73 ± 0.03	8059

1c

Sample	E (%)	Operating State: No B (cpm)	No E^2/B	No E (%)	Yes B (cpm)	Yes E^2/B	Yes (1)	A.E.
20 mL	^3H	54.3	4.70 ± 0.07	600	53.7	2.59 ± 0.05	1100	45%
	^{14}C	79.3	6.10 ± 0.09	1030	79.3	2.56 ± 0.04	2450	58%
	total		24.89 ± 0.17			7.83 ± 0.10		68%
10 mL	$^3H_20$	33.5	3.27 ± 0.05	340	33.4	1.97 ± 0.04	560	40%
5 mL	^{14}C	77.6	3.28 ± 0.05	1830	77.5	0.83 ± 0.03	7250	75%

Note: (1).A.E.: the efficiency of anticoincident.

more than 75%, the background can decrease below 1 cpm. In the ^{14}C channel, although 5cm-thick lead is used to absorb ^{40}K, which comes from the shell of counting tubes, the background is still a bit higher, but it is clear that in general, the result is acceptable. The anticoincident efficiency for tritium is approximately 40%.

Table 2 shows the results from the plastic scintillator AD in different conditions. When all seven detectors are operated (Table 2[A1]), the anticoincident effect is the best. For 20 mL benzene sample, the anticoincident efficiency for blank samples in the total energy channel is about 75%. For empty chambers it is about 87%. The EAC is 2.08 ± 0.03 cpm and the AB is 5.99 ± 0.07 cpm. When only four detectors are operated (Table 2 [B1]), the EAC is 4.18 cpm and the AB is 8.70 cpm. If the same number of detectors operate and there is a gap in the AD ring (Table 2 [A2 and B2, A3 and B3]), with one is on the top of the main detector, and the other below it, the results illustrate that there is no obvious difference between the two conditions. It is proved that the contribution of cosmic radiation is isotroic; the larger the gap, the higher the background.

The results of NaI(Tl) and BGO crystal detectors are shown in Table 3. In

Table 2. The Comparison of Resuts in Various Arrangements of 7 Plastic Scintillator Detectors

Figure 3		AD Operation (Yes or No)		Background (cpm)	cpm of Empty Chamber
A	1	1,2,3, 4,5,6,	Yes	5.99 ± 0.07	2.08 ± 0.03
		7	No	23.76 ± 0.14	15.06 ± 0.08
	2	2,3,4	Yes	7.32 ± 0.05	2.90 ± 0.03
		5,6,7	No	23.75 ± 0.09	14.81 ± 0.07
	3	1,2,3	Yes	8.35 ± 0.07	3.96 ± 0.04
		6,7	No	23.64 ± 0.11	14.98 ± 0.08
B	1	1,2	Yes	8.70 ± 0.06	4.18 ± 0.1
		6,7	No	23.78 ± 0.10	14.87 ± 0.09
	2	1,2,3	Yes	7.16 ± 0.05	2.92 ± 0.05
		5,6,7	No	23.72 ± 0.10	14.82 ± 0.12
	3	2,3,4	Yes	8.50 ± 0.07	3.81 ± 0.04
		5,6	No	23.92 ± 0.11	15.0 ± 0.07
C		1,2,3 4,5,6	Yes	7.52 ± 0.06	3.08 ± 0.05
		7	No	23.82 ± 0.10	14.78 ± 0.10

order to make a comparison, the main experiment results of G-M counting tube and plastic scintillator are also shown in Table 3.

Figure 3 shows all spectra of four anticoincident liquid scintillation counters. There are spectra of anticoincident and coincident background, spectra of empty chamber, and spectra of tritium and ^{14}C.

Table 3. Comparison of Four Types of ADs

		B Total (cpm)	20 mL ^3H E (%)	B (cpm)	E^2/B	10 mL ^3H_2O E (%)	B (cpm)	E^2/B	5 mL ^{14}C E (%)	B (cpm)	E^2/B
A	Y	6.31	53.4	2.16	1320	29.7	1.23	720	80.0	0.54	11852
	N	31.56	53.8	6.03	480	30.0	3.14	290	80.1	4.09	1569
	AE	80%		64%			61%			87%	
B	Y	5.92	50.6	1.83	1400	28.5	1.07	760	74.5	0.40	13870
	N	23.66	51.4	4.15	640	29.4	2.38	360	74.8	2.98	1880
	AE	75%		56%			55%			87%	
C	Y	6.01	48.2	1.73	1343	28.5	1.31	626	76.2	0.55	10557
	N	24.17	48.4	4.13	567	28.7	2.46	335	76.4	2.43	2402
	AE	75%		58%			47%			77%	
D	Y	6.95	52.8	2.32	1200	34.1	1.77	655	74.6	0.74	7520
	N	23.96	52.9	4.04	690	34.2	2.84	410	74.6	3.39	1641
	AE	71%		42%			37%			78%	

Note: A:NaI(T1); B:BGO; C:Plastic scintillator; D:G-M counting tube
Y:operating AD; N:not operating AD;
AE:anticoincident efficiency.

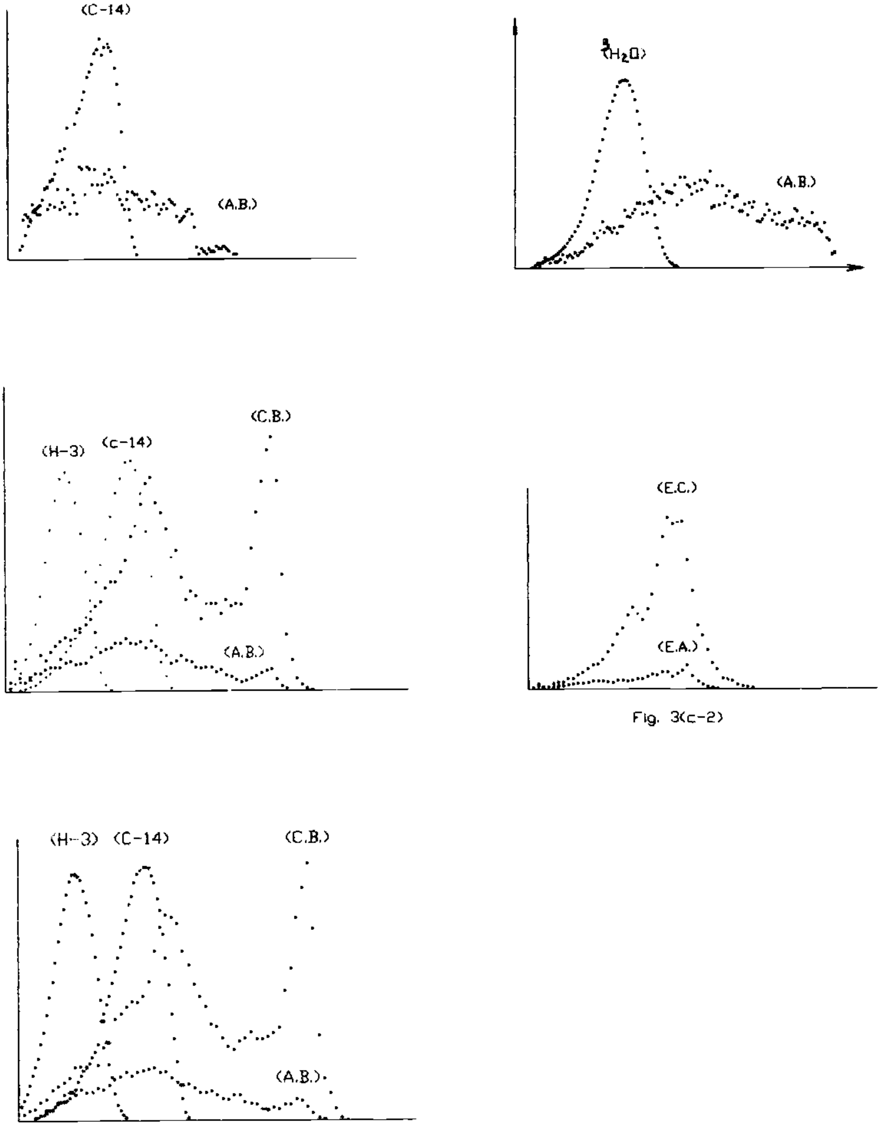

Figure 3. (a). The spectra of Table 3a. (b). The spectra of Table 3b. (c-1). The spectra of Table 3c. (c-2). The spectra of Table 3c. (d). The spectra of Table 3d.

DISCUSSION

From Table 3, except for NaI(Tl) crystal, the other three types of anticoincident detectors all have approximately the same CB, about 24 cpm in the total energy channel. That is to say, these ADs, as matter shielding, not evidently decrease background. For NaI(Tl) crystal, this background is more than 30 cpm. The reason is explained elsewhere.[6] Except for G-M counting tubes, the other types of anticoincident detectors all have almost the same anticoincident background in total energy channel, about 6 cpm. For G-M counting tubes, this background is 7 cpm or so, slightly more than others. From the background spectra, it is shown that μ meson peak is basically elimited. Although the γ efficiency is very low, the main detector is not very sensitive for γ-rays, and the heavy shielding absorbs most environmental radiation. This is the reason why the G-M counting tube can get better effects. The requirement for electronics is very simple and the cost is less than others. In particular, it can be made longer without the price rising too much. So if large vials are used it can provide the cheapest large anticoincident shielding. We think if the longer G-M counting tube is combined with the BGO, perhaps the best result can be obtained.

The plastic scintillator anticoincident detector gives a better result, particularly for measuring tritium. The advantage is clear when comparing with a G-M counting tube, but it is similar to NaI(Tl) crystal, in that more PMTs and complex electronics are necessary and the volume is large. Therefore the matter shielding is larger than others.

The NaI(Tl) and BGO crystals all have high absorption for γ-ray and good data are attained if using one of them as an anticoincident detector. The BGO crystal can more effectively absorb γ-ray and cosmic radiation than NaI(Tl), and it is not hygroscopic and damageable. It is expensive, but only 2 kg are used. The real cost is largely lower than NaI(Tl) because NaI(Tl) crystal weighs 14.5 kg; therefore, a more compact and effective AD can be made of BGO. The disadvantage of BGO is the high cost, therefore large crystals are too expensive to use.

REFERENCE

1. Noakes, J.E., M.P. Neary, and J.D. Spaulding. "Tritium Measurements with a New Liquid Scintillation Counter," *Nucl. Instruments Methods*, 109:177 (1973).
2. Iwakura, T. et al. "Behaviour of Tritium in the Environment," IAEA-sm-232:63 (1979).
3. Rajamae, R., et al. *Radiocarbon*, 22(2):435 (1980).
4. 1220 Quantulus A multi-parameter low level LSC system from LKB-Wallac.
5. Jiang Hanying et al. "Model DYS Low-Level Liquid Scintillation Counter," in *Advances in Scintillation Counting*, (Edmonton, Canada: University of Alberta, Edmonton, 1983), pp.478–493.
6. Jiang Hanying and Lu Shao-wan. "The Effect of Altitute on the Background of Low-Level Liquid Scintillation Counter," in *An International Conference on New Trends in Liquid Scintillation Counting and Organic Scintillators* (1989).