

The Effect of Altitude on the Background of Low-Level Liquid Scintillation Counter

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ABSTRACT

The background counting rate increases more than 100% in Xining over Beijing for the same low-level liquid scintillation counter with NaI(Tl) anticoincident shield. Another experimental counter with bismuth germanate(BGO) anticoincident shield has been transported to Xining, and a series of experiments have been performed. The source of the increasing background is analyzed and the methods of decreasing the background are provided.

The altitude of Xining is 2000 meters higher than Beijing, so the earth surface intensity and the constituent of cosmic rays is different in the two cities. Based on our experiments, it seems that the increasing background rate in Xining is not only due to the increased cosmic ray intensity, but also due to the high atomic number of shielding material, e.g., NaI(Tl), BGO, and lead. It is possible that most of the increasing background comes from the interaction between cosmic rays and shielding material. Appropriate selection of shielding material can weaken the effect of the interaction and decrease the background.

INTRODUCTION

The first low-background liquid scintillation counter with an anticoincident shielding was developed by J.E. Noakes.¹ Following a growing application and requirement of the radioisotopes, such as ¹⁴C and tritium, in the fields of geohydrology, geography, geology, archaeology, and others, many types of low-level liquid scintillation counters² with various anticoincident shielding have been rapidly developed. Most of them are used at elevations in the hundreds of meters. It is interesting to find what will happen when an instrument is operated at an elevation of more than one thousand meters. In 1985, a model DYS-3 low-background liquid scintillation counter with a NaI(Tl) crystal as an anticoincident shielding was transported to the Institute of Qinghai Salt-Lake. We found that the background in Xining increased more than twofold. We completed a series of experiments to find out how environmental radiation affects background. From the experimental results, it is thought that the increasing background in Xining is mainly due to the interaction between

cosmic rays and shielding materials (lead and NaI(Tl)). If the shielding material is appropriately readjusted, the background can be obviously decreased.

INSTRUMENTS

The Model DYS-3 automatic low-level liquid scintillation counter was made at the Institute of Biophysics, Academia Sinica, Beijing. A sketch of the detector is shown in Figure 1. An annular NaI(Tl) crystal (< 200 mm OD, 80 mm ID and 150 mm in length) with a ϕ 50 mm is used as an anticoincident detector. The sample is elevated from the changing machinery to the sample chamber through the hollow. The matter shielding is 10-cm-thick lead. The changing of sample, data acquisition, and processing are automatically completed by an APPLE II microcomputer.

An experimental installation with bismuth germanate(BGO) crystal is the anticoincident shielding. Several pieces of BGO are in a $100 \times 100 \times 100$ mm cubic case. A ϕ 60 mm hollow in the middle of the cuboid is for placing the sample chamber and PMTs and a ϕ 30 mm hollow of the case over the sample

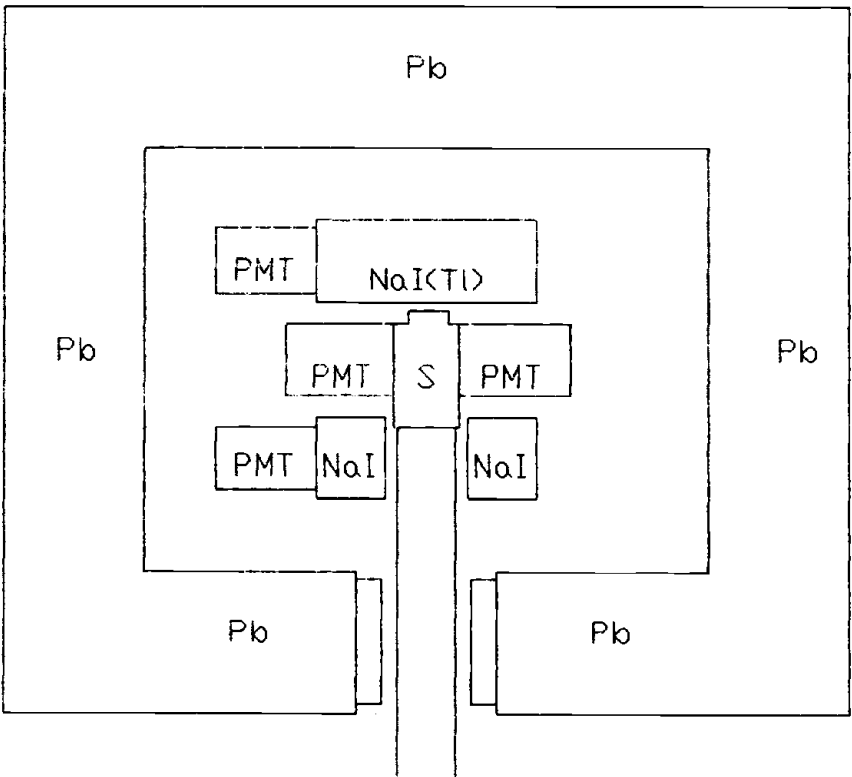


Figure 1. DYS-3 detector made at the Institute of Biophysics, Academia Sinica.

chamber is for changing the sample. The weight of the BGO crystal is about 2 kg. Two windows (ϕ 50 mm) on the surface of the cuboid allow for two PMTs to collect the photons from the BGO (Figure 2). The matter shielding is 10-cm-thick lead.

An experimental installation with plastic scintillator is an anticoincident shielding. Most of it is the same as the DYS-1,³ except for the anticoincident shielding. It consists of seven detectors in annular. Each one has a ϕ 76 \times 150 mm cylindrical plastic scintillator and a PMT.

EXPERIMENT AND RESULT

The blank sample is 20 mL benzene scintillation cocktails (5 g PPO + 0.05 g POPOP/1 benzene) in a 20 mL quartz vial. The vial is sealed by 914 adhesive agent. All of the counters are operated at high voltage for tritium measuring. The background counts per minute are measured in total energy channel. If

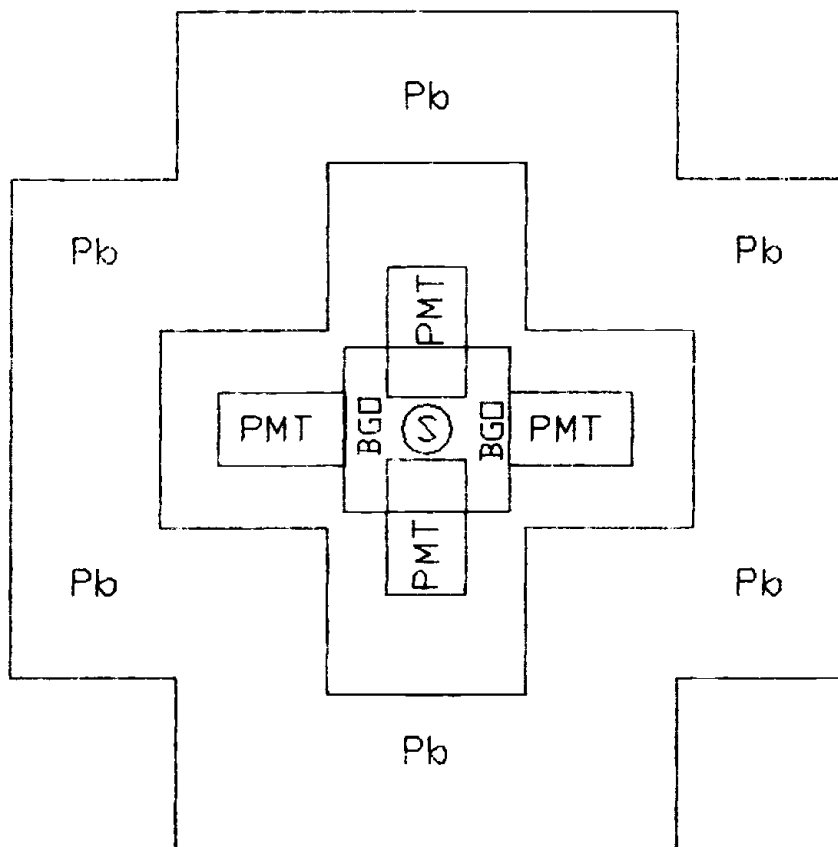


Figure 2. BGO experimental installation.

Table 1. The Comparison of the Background in Beijing and Xining

	DYS-3				BGO Installation			
	CB	AB	EB	EA	CB	AB	EC	EA
Beijing	30.19	5.64	18.07	1.44	24.40	5.39	15.63	1.32
Xining	71.47	13.75	29.95	1.75	55.88	17.11		

Note: E.C.: empty sample chamber C.B.; E.A.: empty sample chamber A.B.

the anticoincident detector does not operate, the background measured is named by coincident background (CB). If the anticoincident detector operates, the background measured is named by anticoincident background (AB). When there is no sample in the sample chamber, the counting rate is named by empty chamber background (separately ECB and EAB).

The experiments are done separately in Beijing (the elevation is about 100 meters, 40° N) and in Xining (the elevation is about 2300 meters, 36.5° N). The background and the empty chamber counting rate are measured first in Beijing and then in Xining. The results (Table 1) show the AB of two counters all increase about threefold.

The shielding experiments are completed in a BGO installation in Xining. All of the experimental results are listed in Table 2. We find, if the lead shielding is increased from 10 cm to 20 cm, the background increases. The CB increases from 55.88 cpm to 59.44 cpm and the AB increases from 17.11 cpm to 19.49 cpm. If we append the lead with plastic material (polystyrene) and water, the CB decreases to 50.37 cpm and AB decreases to 14.20 cpm. The 10 cm lead chamber is enlarged to test the radon effects on the background. There

Table 2. The Data of the Shielding Experiments in Two Places

	Place Shielding Condition	Xining		Beijing	
		CB	AB	CB	AB
BGO installation					
A	Only 10 cm lead under the detector	295.5	171.7	300.8	163.8
B	Only 20 cm lead under the detector	338.9	198.6		
C	Entire 10 cm lead shielding	55.88	17.11	24.40	5.39
D	C + appending 10 cm lead on top	57.07	17.68		
E	C + appending 10 cm lead around	59.44	19.49		
F	C + many polystyrene pellets fills the empty space of the lead chamber and 30 cm thick polystyrene on top of and 60l water around the lead chamber	50.37	14.20		
G	Enlarged 10 cm lead chamber	54.90	17.93		
H	G + 30 kg. paraffin wax and polystyrene fills the empty of the lead chamber	44.77	10.57		
I	H + 60 L water + 60 kg. paraffin wax around and on the lead chamber	44.65	9.67		
DYS-3					
	10 cm lead shielding	71.47	13.75	30.19	5.64
	The empty of the lead chamber are filled with 30 kg. of paraffin wax	58.00	9.41		

Table 3. The Estimated Intensity of the Cosmic Rays at 50° N

	Sea Level	2000 meters Elevation	800 g/cm ² Atmosphere
Total intensity (particles /sec.cm ² , in all directions)	0.020	0.035	
Hard constituent (particles /sec.cm ² , in all directions)	0.013	0.018	
Soft constituent (particles /sec.cm ² , in all directions)	0.007	0.017	
E: electron and positron with energy more than 10 MeV	$1 \times 10^{-3}/\text{cm}^2.\text{sec}.\Omega$		$6 \times 10^{-3}/\text{cm}^2.\text{sec}.\Omega$
μ : μ mesons with various energy	$8 \times 10^{-3}/\text{cm}^2.\text{sec}.\Omega$		$1.5 \times 10^{-2}/\text{cm}^2.\text{sec}.\Omega$
P: proton with energy more than 400 MeV	$3 \times 10^{-5}/\text{cm}^2.\text{sec}.\Omega$		$2 \times 10^{-4}/\text{cm}^2.\text{sec}.\Omega$

are 10 cm empty spaces above and under the detector. The background obviously does not change, but if the empty spaces of the lead chamber are filled by 30 kg paraffin wax, the background decreases. The CB decreases from 55.88 cpm to 44.77 cpm; the AB decreases from 17.11 cpm to 10.57 cpm.

If the empty space of the lead chamber of DYS-3 is filled with paraffin wax, the CB of DYS-3 decreases from 71.47 cpm to 58.00 cpm; the AB of DYS-3 decreases from 13.75 cpm to 9.41 cpm.

DISCUSSION

Comparing the empty chamber background in two places (Table 1), we find the CB of the empty chamber of DYS-3 in Xining is 1.66 times higher than that in Beijing, but the AB of the empty chamber in Xining is only 1.22 times higher than in Beijing. Table 3 shows that the total intensity of various energy μ mesons is 1.88 times higher at the elevation with 800 g/cm atmosphere (or elevation of 2000 meters or so) than at sea level. According to our past experiments, most contributions of the μ mesons to the background can be eliminated by any type of anticoincident detector; thus it is suggested that the background of the empty chamber in coincident counters at sea level is mainly from the μ mesons of cosmic rays. The increasing background of the blank sample in Xining mainly does not come from the increasing μ mesons.

In Beijing, most of the low-level liquid scintillation counters with different anticoincident detectors all have a CB value of about 24 cpm. The counter with NaI(Tl) crystal as an anticoincident detector, however, has a CB of about 30 cpm; it is 6 cpm higher than the others. In the past we thought this came from the ⁴⁰K in NaI(Tl). Now, from Table 2, under the same experimental condition, the CB of DYS-3 is 15.6 cpm higher than the CB of BGO installation in Xining. Obviously, it can not be assigned the ⁴⁰K of the NaI(Tl). Maybe it comes from the interaction between NaI(Tl) crystal and some high energy

Table 4. The Anticoincident Effect of Two Detectors for Neutron

	Coincident Counting Rate for Neutron (cpm)	Anticoincident Countingrate for Neutron (cpm)	The Anticoincident Effect for Neutron
BGO installation	214.2 ± 1.5	158.1 ± 1.3	19.5%
Plastic scintillator installation	186.9 ± 2.7	81.6 ± 1.4	53.3%

particles in cosmic radiation; new radiation is created, and it increases the background.

In Xining, the greater the lead thickness, the greater the background. In Beijing, the background decreases if the lead thickens.² When the lead is only placed under the detector and there is no lead above and around the detector, the background is obviously no different in two places, but the difference rapidly increases as the thickness of the lead increases. From this, we think the increasing background is partly from the interaction between the lead and high-energy cosmic radiation. When a particular cosmic ray shoots the lead, it produces heavy radiation.

If the empty space between the detector and lead is filled with paraffin wax, the background decreases. We feel the interaction between cosmic radiation and lead produces a nuclear reaction, and a lot of neutrons are produced. The difference between CB and AB, after and before being filled with paraffin wax for DYS-3, is respectively 13.47 cpm and 4.34 cpm. It means the effect of anticoincidence of NaI(Tl) for this part of the background is about 68%. For BGO installation, the difference of the CB and AB after and before being filled with paraffin wax is 10.13 cpm and 7.37 cpm, respectively; the effect of anticoincidence is only about 27.2%. In Beijing, 5×10^5 /sec Am-Be neutron (in the state for transportation) is placed out of the anticoincident counters of BGO and plastic scintillator, and the counting rate is measured with the same condition as above. The results are shown in Table 4. From Table 4, the anticoincident effect for BGO and plastic scintillator is 20% or so separately and more than 50% combined. We think it probably depends on the volume, the atomic number and geometric condition of the anticoincident detector, and also the energy spectrum of the neutron and the interaction between neutron and matter. According to the experimental results, the increasing background can be decreased by paraffin wax, and there is a difference of anticoincident effect between two counters in Xining. We consider that the increasing background is due to the neutrons produced by the lead interacting with the cosmic radiation. The other part of the increasing background for DYS-3 is difficult to decrease. It comes from the interaction between the NaI(Tl) and cosmic radiation.

To sum up, plastic scintillators have better anticoincident effect. When interacting with cosmic radiation, it does not produce much second radiation; it does not lead to increased background for liquid scintillation counters as

NaI(Tl) crystal does. In a high elevation area, as an anticoincident shielding, it is better than NaI(Tl). A complex matter shielding of lead and paraffin wax for a liquid scintillation counter is necessary.

REFERENCES

1. Noakes, J.E., M.P. Neary, and J.D. Spaulding, J.D. "Tritium Measurement with a New Liquid Scintillation Counter," *Nuc. Instrum. Methods*, 109:177 (1973).
2. Yang Shouli, Jiang Peidong, and Lin Han. "The Advance and Application in Liquid Scintillation Measurement Technique," p.88 (1987).
3. Jiang Hanying et al. "Model DYS Low-Level Liquid Scintillation Counter," in *Advance in Scintillation Counting* (S.A. McQuarrie, et al.: (Ed. Edmonton, Canada: University of Alberta, 1983).

