Low Level/Low Background Counting

Detector Applications Information Note

Introduction

Low level/low background counting applications include gamma and X-ray astronomy (balloon-borne or orbital missions to examine distant sources), alpha/beta wipe sample counting, charcoal canister counting (to determine radon levels), and animal or whole-body counting.

The detection of gamma- or X-ray radiation from samples containing only traces of radioactive materials is often troublesome because of the presence of background radiation. When a sample is counted, the resulting data always contains two components. One component is the radiation emitted by the sample; the second component is background radiation. Background radiation is generally defined as radiation which causes counts in the region of interest but is not emitted by the sample being counted (e.g., from surroundings, cosmic quanta, the materials making up the detector).

The data resulting from counting a sample is the *gross count rate.* When the *background count rate* is subtracted, a *net count rate* is found. Finding this *net count rate* is the purpose of the measurement. The comments, "I have a low background application", or "I want a low background detector", are an indirect way of saying, "I want to count a sample having a very small *net count rate*. Therefore, I want a detector with a small *background count rate* and correspondingly low statistical variance. This ensures that background statistics are not large and will not obscure the counts from my sample."

To illustrate a practical example, SGC has published an application note which presents a statistical approach to a whole body counting application (See Application Note entitled "Whole Body Counting.")

The lowest sample radioactivity that can be measured is directly dependent on the background count rate of the detector (the detection system). The background count rate of the detector is reduced by:

1) placing the detector in a heavy shield, and/or
2) selection of the various component parts used to build the detector.

Table 1 shows the background count rate of several NaI(Tl) detectors, unshielded versus shielded. The measurements were taken outside our Low Background Chamber (LBC) and then inside. The LBC is made from pre-WW II steel, layers of 99% pure virgin lead, and OFHC copper linings. The data is a good representation of the effectiveness of shielding in general and of our LBC in particular.

Table 1

Detector Size Dia. x Length	30 keV to 2 MeV Unshielded	Count Rate Shielded
2" x 2"	185 cps	2.7 cps
3" x 3"	421 cps	4.4 cps
4" x 4"	681 cps	5.1 cps
6" x 3"	990 cps	7.3 cps
5" x 5"	1290 cps	14.6 cps

Low Background Detectors

The background count rate and the associated counting error determine the measurement sensitivity limit of a sample's activity. Therefore, detectors for low level/low background applications should have a low inherent radioactivity to minimize their contribution to the background count rate. These detectors usually are made with low background stainless steel or electrolytic copper housings. All other detector materials (including the photomultiplier tubes) are tested and selected for the lowest possible inherent radioactivity.

In addition, light-pipes of quartz or pure NaI may be used to provide a γ-ray absorber between the photomultiplier tube and the scintillation crystal. The materials used to make photomultiplier tubes (especially the glass) contains potassium. The isotope K-40 is a significant source of background radiation. PMTs with low potassium content are available.

Table 2 shows the radioactive contamination found in some typical detector components as measured in SGC's Low Background Chamber. A special, low background NaI(Tl) detector with NaI(Tl) and BC-412 annular anti-coincidence shields was also used inside the LBC to make some of the measurements.

Note, in particular, the radioactivity present in a standard 3" PMT. The K-40 content in this PMT would make it an unlikely candidate for use in a whole body counting application where total body potassium is the measurement of interest. Note that the detector count rate is much lower than the sum of the radioactivity of the various components:

Counts per time ~ efficiency x disintegrations per time.

For example, PMTs, windows, reflectors and other assembly components are only at the surface of the NaI(Tl) detector (except for well geometries) and thus the efficiency is less than 50% for the emissions from those components.

The detector's efficiency is dependent on geometry, thickness of the detector in the direction of the emitted gamma ray, and other factors. For low level or low energy sources, the detector should be placed close to the source being counted.

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Low Level/Low Background Counting

HPGe Detector Systems

The excellent resolution of a high purity germanium (HPGe) detector reduces the minimum counting time necessary to identify an activity in the sample. However, in a HPGe detector, Compton scattered γ-rays and cosmic ray muons produce substantial additions to the background seen in the spectrum. Using NaI(Tl) or BGO anti-coincidence shield detectors with the HPGe detector helps reduce these contributions to the background.

As with other detectors, reducing the background count rate further by using low inherent background materials in the detectors and placing the detector system in a heavy shield is essential to effective low level counting with HPGe systems.

Low Energy, Low Level Counting - Phoswich Detectors

Phoswich designs frequently are used to reduce background in low-energy gamma and X-ray counting applications. In these configurations, a thin NaI(Tl) scintillator has its thickness optimized for the region of interest. The thin scintillator is optically coupled to a thicker "guard" crystal, e.g. CsI(Na), which has a different pulse characteristic. This phosphor "sandwich" is then read out by a common PMT. For detectors made with Beryllium entrance windows, **Table 3** lists the approximate direct contributions to the background. The density of these windows is about 1.8g/cc.

Pulse shape discrimination electronics differentiate the signals from the principal and guard crystals. By using the guard crystal in the anti-coincidence mode, events that occur simultaneously in both crystals are vetoed, reducing the background and Compton contributions to the region of interest.

Phoswiches can be configured from other scintillator combinations for specific applications. For example, simultaneous alpha, beta, and gamma counting is achieved using a single detector comprised of CaF_2(Eu) and NaI(Tl).

Table 2

Component/Material	Unit	Ra-226	Th-228	K-40	Cs-137	Co-60
Quartz - fused silica	pCi/kg	<4.5	<8.6	<54		
Quartz	pCi/kg	<3.9	<8.1	<0.43	<2.8	<3.1
OFHC copper	pCi/kg	<5.4	<8.6	<63		
Copper	pCi/kg	<8.4	<3.1			
Teflon tape (0.1mm)	pCi/cm^2	0.006 ±0.005	0.012 ±0.005	<0.0015		
Mu-metal shield (3")	pCi/piece	4.4 ±0.5	<0.01	9.5 ±3.3		
3" PMT	pCi/each	7.2+/0.6	1.4+/-0.4	96+/-3.7		
Silicone grease	pCi/kg	<0.315	<0.59	<3.6		
Pre-WWII steel	pCi/kg	<4.5	<6.3	<45		
Mylar sheets	pCi/kg	<8.4	<8.9			
BC-408 scintillator	pCi/kg	<0.90	<0.62	<7.2	0.94±0.34	0.28±0.18
Stainless steel	pCi/kg	<23	<19	<144	10±5	8.1±3.9
A-lead	pCi/kg	<0.84	<1.1	<11	0.58±0.44	6.0±0.5
Aluminum foil	pCi/kg	<0.30	0.35±0.12	<2.4	0.22±0.10	0.12±0.07
Note: 1 pCi - 2.22 disintegrations per minute (dpm)<indicates a range: the value stated is the maximum						

Table 3
Approximate Contribution to Background (cpm/gram)

Energy Range	Standard Be	High Purity Be
12-25 keV	2.6	0.04
50-70 keV	0.8	0.05
10-200 keV	7.7	0.26

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