Performance of Sodium Iodide, BrilLanCe™350 and BrilLanCe™380 for High Count Rate Applications

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Technical Information Note
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Executive summary

This report presents experimental results of the study of Sodium Iodide (NaI), BrilLanCe™350 (B350) and BrilLanCe™380 (B380) performance for counting applications. Results indicate the ability of the BrilLanCe detectors to handle significantly higher count rates than NaI detectors.

Motivation

Performance of NaI, B350 and B380 crystals in counting applications has been studied. NaI crystals have a decay time of ~250 nanoseconds, while 28 nanoseconds is a typical decay time of B350 ($LaCl_3$) and 16 nanoseconds for B380 ($LaBr_3$). This difference becomes crucial at high gamma ray fluxes, specifically when count rate of the gamma photons registered by the detector is on the order of $1/\tau$, where τ is a characteristic time of the scintillation pulse. Thus, BrilLanCe detectors could be expected to operate at up to 10 times higher flux than traditional NaI detectors.

Test set-up

The test set-up shown in Figure 1 uses the RCA 8575 PMT without coupling grease. The PMT pulse was smoothed by the timing filter amplifier (TFA), ORTEC 474. Attempts to perform counting without smoothing of the PMT pulses failed due to stochastic noise providing false triggers fluctuating above the lower level discriminator (LLD) of the Constant Fraction Discriminator (CFD).

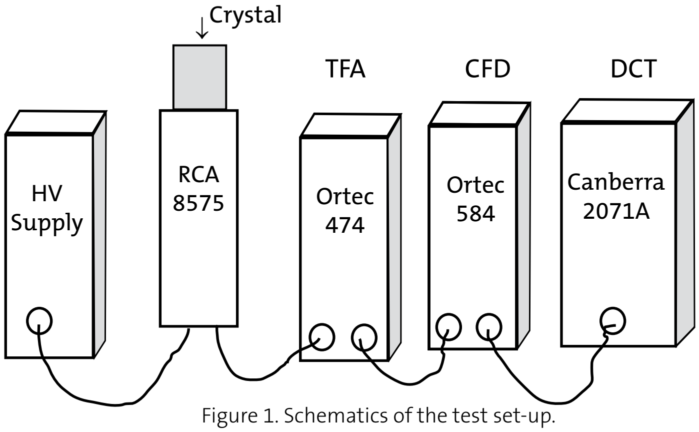

Figure 1. Schematics of the test set-up.

A CFD, ORTEC 584 was used to eliminate low-level PMT noise. Counting of the pulses was performed by dual counter timer (DCT), Canberra 2071A. All three tested crystals had the same geometry, right-circular cylinders with diameter 2.5 cm and length 2.5 cm. Crystals were irradiated with Cs-137 (662 keV) and Co-57 (122 keV) sources.

Measurements

First, the plateau curves were measured for Cs-137 and Co-57 sources. Lower level discriminator levels and integration/differentiation constants used in the experiments are shown in Table 1. Note that integration and differentiation times for NaI detector are different from BrilLanCe detectors due to difference in the PMT pulses lengths for NaI and BrilLanCe detectors. Plateau curves are shown in Figures 3 and 4 for Co-57 and Cs-137 respectively. High voltages corresponding to the center points on the plateaus were chosen as operating voltages for count rate experiments. This was done to ensure that the same fraction of the spectrum above the

		DCT Setting	TFA Settings		PMT setting
		LLD, mV	T_{int}	T_{diff}	Plateau HV, V
Co-57	NaI	50	100	50	-1975
	B350	50	20	–	-1775
	B380	50	20	–	-1725
Cs-137	NaI	100	100	50	-2200
	B350	100	20	–	-1800
	B380	100	20	–	-1900

Table 1. Parameters of the experimental system

LLD was available for sampling. This accounts for differences in light yield among the different scintillators.

Three 90 µCi Cs-137 sources and one 250 µCi Co-57 source were used in the experiments. Intensity of the gamma radiation incident upon the detectors was controlled by the distance from the source to the crystals, and in case of Cs-137, also by changing the number of sources used at a time. A sketch of the geometry is shown in Figure 2. Results of the measurements are shown in Figures 5 and 6 for Co-57 and Cs-137, respectively, as a function of the count rates measured experimentally vs. the true count rates.

True count rates were estimated by the following method. Count rates from a weaker 10 µCi Cs-137 source were measured by a B380 detector with the source at the same locations as in the count rate test with a hotter source. This counting system with a 10 µCi source was far from the saturation regime and, therefore, measured count rates for this weak source are essentially equal to true count rates. Because the positioning of the high intensity sources were the same as the low intensity source, true count rates for these two configurations would differ only by a constant factor for each position. This constant factor was obtained using measured count rates for the farthest source positions, where measured count rates were close to the true count rates even for hotter sources. Thus, true count rates for hotter sources were deduced from the measurements of the count rates due to a less intense source.

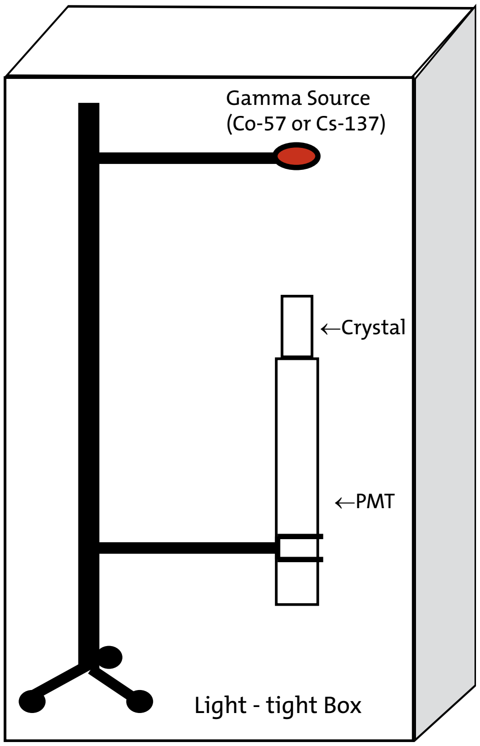

Figure 2. Geometry of the test set-up

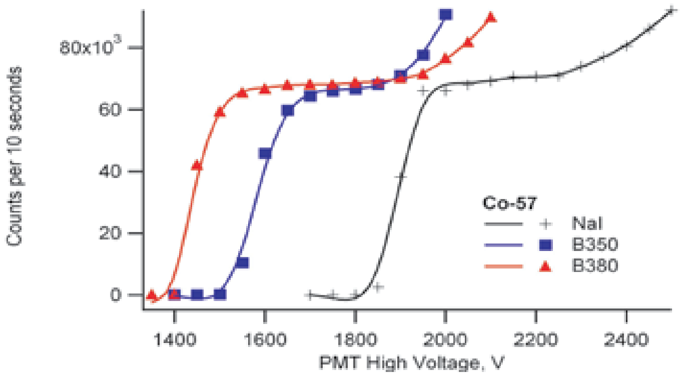

Figure 3. Co-57 plateau curves for NaI, BrilLanCe 350 and BrilLanCe 380 detectors

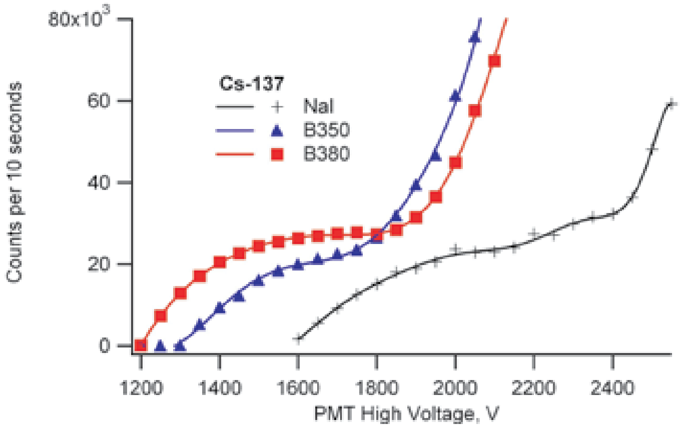

Figure 4. Cs-137 plateau curves for NaI, BrilLanCe 350 and BrilLanCe 380 detectors.

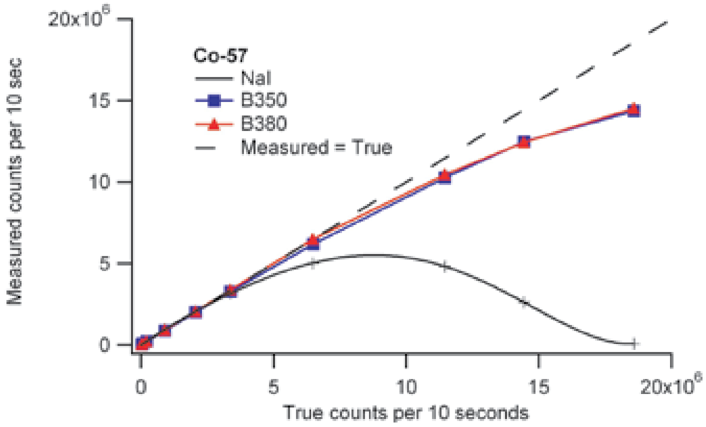

Figure 5. Counts from Co-57 source as measured by NaI, BrilLanCe 350 and BrilLanCe 380 detectors.

Results

Two aspects of the counting abilities of BrilLanCe and NaI detectors at high gamma radiation flux were considered in this study. Firstly, what is the highest count rate that can be registered by each detector? As the gamma flux increases, count rate in a detector increases as well up to a certain maximum. If flux is further increased, count rate drops because of the pile-up of the scintillation pulses. In other words, at very high gamma flux, two or more pulses can merge in such a way as to be counted as only one pulse. The ratio of the maximum count rates for any two detectors can then be considered as a measure of relative performance. Note, that different detectors reach maximum number of counts at different fluxes. In the case of the NaI detector, we were able to obtain a maximum number of counts experimentally, as can be seen in Figures 5 and 6. However, the count rate for BrilLanCe detectors was rising with gamma flux up to the maximum flux achievable with available sources. Therefore, only the lower limit for the ratios of maximum counts B350/NaI and B380/NaI can be established based on the gathered experimental data. As can be seen in Figures 5 and 6, BrilLanCe detectors can count 122 keV gamma rays at least 3 times faster then NaI. The relative factor for 662 keV gamma rays is at least 6. It is possible that the count rate improvement is greater than this at even higher count rates. However, due to the unavailability of the stronger Cs-137 and Co-57 sources, we were unable to probe this region.

The second question that can be addressed is how much faster can BrilLanCe detectors count relative to the NaI detectors at a given flux? Although this question seems to be very similar to the last one, the answer is drastically different. Because saturation of the NaI detector occurs at a much lower flux than the BrilLanCe detectors, the ratio BrilLanCe/NaI at the same flux can be as high as 700 when NaI detector pulses are piling up, while BrilLanCe detectors are more or less in a linear regime. As can be seen on Figures 7 and 8, the ratios slowly increase with increase in true count rates from ~1 at low count rates to ~2 at the flux where the NaI detector reaches maximum count rate (at ~7×10^5 counts per second for Co-57 source and ~2×10^5 counts per second for Cs-137). As the flux increases further, the ratios grow very fast, growing by factors of hundreds while the true count rate increases by a factor of 2 to 5.

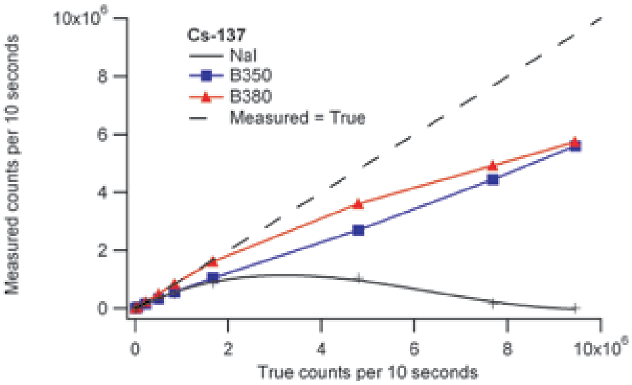

Figure 6. Counts from Cs-137 source as measured by NaI, BrilLanCe 350 and BrilLanCe 380 detectors.

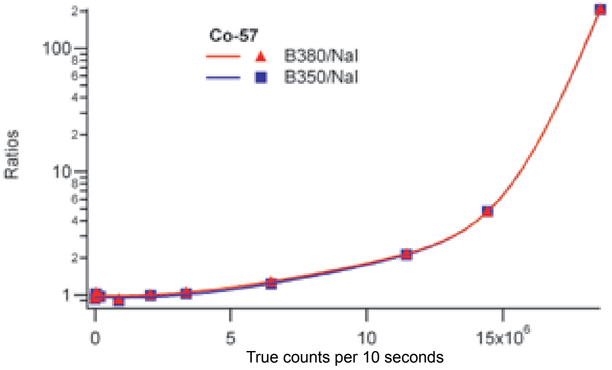

Figure 7. Ratio of the count rates from Co-57 measured by BrilLanCe 350, BrilLanCe 380 and NaI detectors as a function of true count rates.

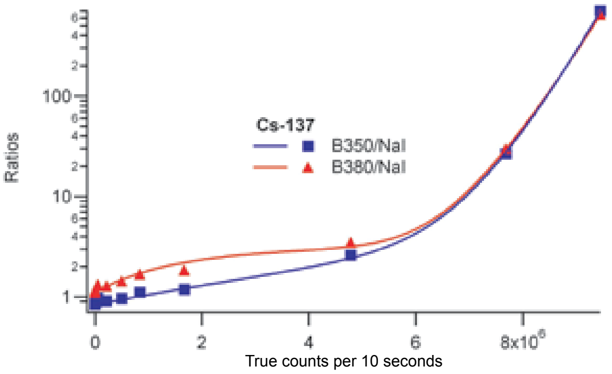

Figure 8. Ratio of the count rates from Cs-137 measured by BrilLanCe 350, BrilLanCe 380 and NaI detectors as a function of true count rates.

Conclusions

A comparative study has been performed to investigate the performance of BrilLanCe and NaI detectors in counting applications at high gamma radiation fluxes. 122 keV (Co-57) and 662 keV (Cs-137) gamma ray sources were used in the experiments. Expectations of superior BrilLanCe performance due to a much shorter decay time than NaI have been confirmed experimentally. The NaI detector starts to lack in performance at ~500 kHz counting rate for Co-57 and at ~200 kHz for Cs-137. As the radiation flux increases further, the NaI measured count rate drops due to the scintillation pulses pile-up while BrilLanCe detectors' count rates are increasing consistently with the increase in flux. At the scintillation rate of ~1.8 MHz, the counting system with the BrilLanCe detectors and the Co-57 source counted as much as 200 times faster than the similar system with the NaI detector. Similarly, at ~1 MHz the scintillation rate BrilLanCe system counted 700 times faster than the NaI system.

Protected under patents US7,067,816B2, US7250609B2, EP1257612B1,EP1516078B1, ZL03813659.7,UA75066C2,US7067815B2,US7233006B2,EP1255796B1*, EP1516078B1,ZL01805267.3,ZL03813659.7,EP1516078B1,UA75591C2,UA75066C2*
**These original patents were granted to Stichting Voor de Technische Wetenschappen. Inventors are P. Dorenbos, C.W.E. van Eijk, H.U. Gudel, K.W. Kraemer, E.V.D. van Loef.*
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