Optimization of performance and calibration of LBC detector

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A lanthanum bromochloride (LBC) scintillation detector [1-2] was acquired for gamma-ray spectroscopy of devices activated by cyclotron beams at the Radiation Testing Facility [3]. The detector is a 2" diam. x 2" crystal of $LaBr_{2.85}Cl_{0.15}$:Ce (density 4.90 g/cm^3), coupled to a photomultiplier tube (PMT). The tube is plugged into the socket of a PMT base integrated with a power supply, an amplifier, an analog-to-digital converter, and a multichannel analyzer (MCA) [4]. The crystal and the PMT are encapsulated in 0.4 mm thick aluminum to protect the detector from ambient light and moisture and to reflect the scintillation light.

Since there are no manual controls for the supporting electronics, everything has to be set with software. This can be done using a basic data-acquisition and analysis package that came with the detector [5] or with a more sophisticated program that was purchased separately [6]. However, neither the manufacturer nor the supplier provided the recommended settings for the LBC detector and so all the performance-affecting parameters had to be optimized using trial-and-error method. The only exception was the PMT bias, for which the manufacturer recommended the value of 700 V, but without any explanation of what happens if the detector is slightly under-biased or slightly over-biased. Unfortunately, at 700 V and at the lowest signal amplification the last channel in the spectrum corresponds to about 1250 keV, which severely limits usefulness of the apparatus. Consequently, we kept signal amplification at its minimum value and lowered the bias in order to increase the energy range. After it was verified that the bias-dependence of gamma-ray peak widths (measured in keV) is negligible, it was decided to conveniently set the bias to 643.7 V, so that on the 2048-channel full scale the channel width at the low-energy side of the spectrum corresponds to 1 keV. With the intrinsic non-linearity of the energy scale, *i.e.*, slightly reduced gain on the high-energy side of the spectrum, the resulting energy range was 2064 keV. Of course, the detector bias can be lowered even further if an increased energy range is needed.

Other parameters important to performance of the data-acquisition hardware include the lower-level discriminator (LLD), the digital threshold (DT), rise time (RT) of the signal and flat-top width (FTW) of the signal. LLD is set in channel units and results in a sharp cutoff on the low-energy side of the spectrum. It was set to channel 37 in order to avoid processing of the strong peaks due to $K\alpha$ x rays of barium, lanthanum and cerium (which are always present as a part of the detector's intrinsic background), while enabling detection of most of the corresponding $K\beta$ x rays (which are much weaker). Cutoff produced by DT is gradual. Consequently, DT was set to the channel value of 8, so that it has no effect on channels above 37.

RT and FTW are signal-shaping parameters that can have a substantial direct effect on resolution and dead time and an indirect effect on gain. Their values were varied independently and simultaneously in order to keep the resolution at the value specified by the manufacturer, while minimizing the dead time and maximizing the gain. This was done at the incoming counting rate (ICR) of about 10,000 events per second (10 kcps). We found that the optimal values of RT and FTW were 1.56 μs and 0.48 μs, respectively, which resulted in the dead-time losses of about 4.7%.

Detection efficiency was determined in a series of measurements with calibrated (almost) point-like sources in order to establish its dependence on photon energy, source-to-detector distance, and displacement from the detector axis. The efficiency was also calculated using CYLTRAN, a Monte Carlo electron-and-photon transport code [7].

Detection efficiency as a function of photon energy was measured with sources of ^{109}Cd (4.62 μCi), ^{137}Cs (0.1 μCi), ^{60}Co (0.69 μCi), ^{133}Ba (1 μCi), ^{152}Eu (1.032 μCi), and ^{207}Bi (1 μCi) placed at the distance of 5 cm from the detector on the detector axis. The listed source activities refer to the date of their calibration. Nominal diameters of the sources were 3 mm. The results are shown in Fig. 1.

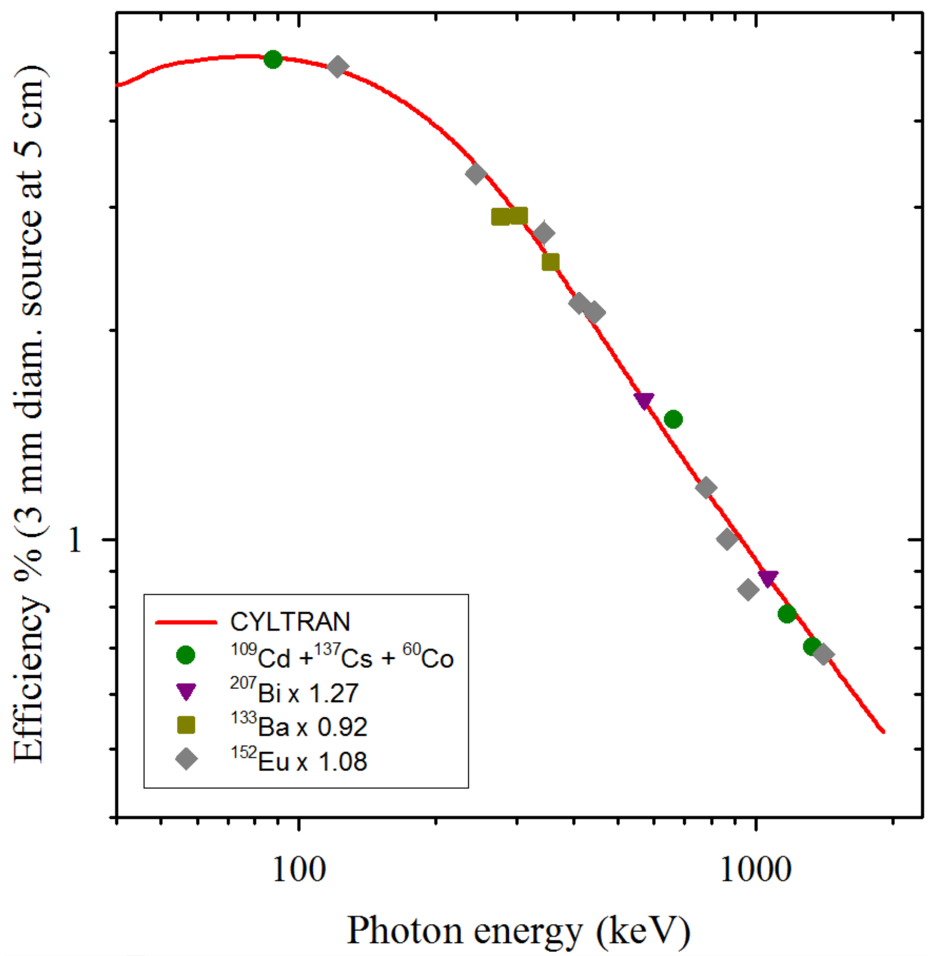

Fig. 1. Measured and calculated LBC detector efficiency as a function of photon energy.

Fig. 1 shows that CYLTRAN calculations are in excellent agreement on absolute scale with measurements involving the sources of ^{109}Cd, ^{137}Cs, and ^{60}Co. The results of the measurements with the remaining three sources had to be slightly scaled in order to agree with the calculations. This correction for ^{133}Ba and ^{152}Eu results was -8% and +8%, respectively, while the correction for ^{207}Bi results was

+27%. These corrections are not unexpected considering typical tolerances in activities of calibrated sources [8]. The larger correction for ^{207}Bi (an open source) results may also indicate that some of the radioactive material may have been removed over time.

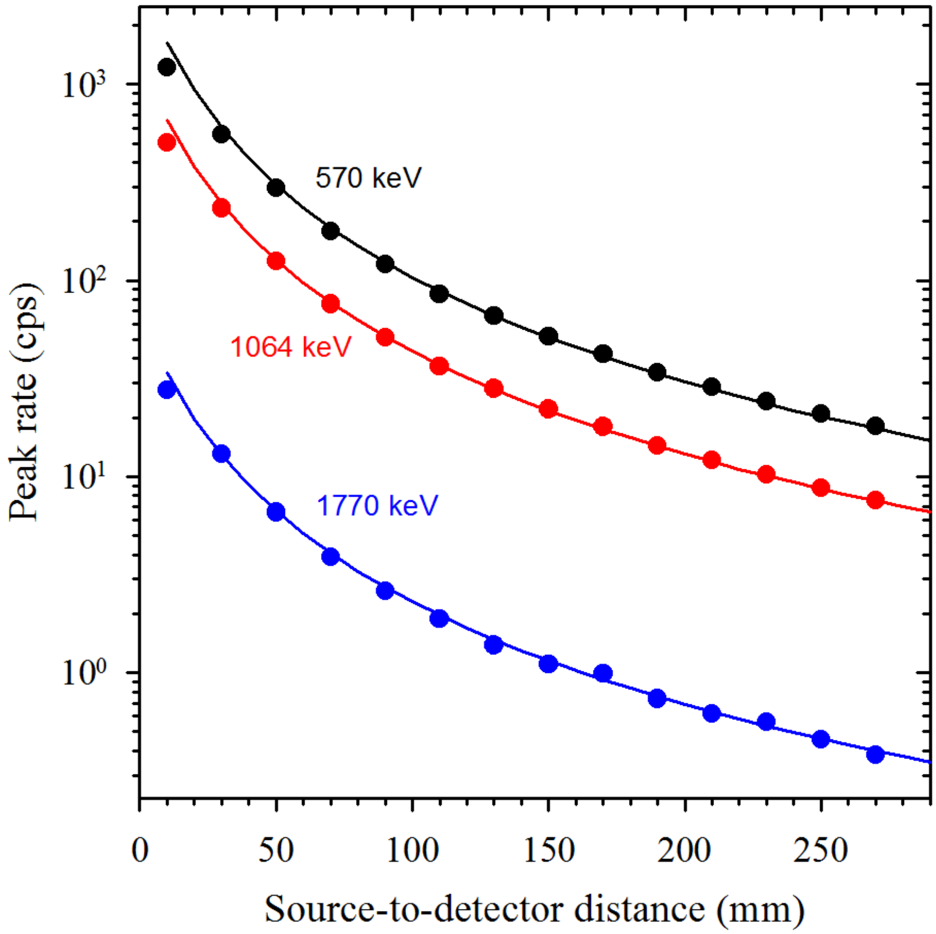

Fig. 2. Measured and calculated LBC detector efficiency as a function of source-to-detector distance.

Since it was established that CYLTRAN calculations are in excellent agreement with measurements on the absolute scale, the remaining calibration measurements and related calculations were compared by renormalizing one set of results relative to the other. Fig. 2 shows how the efficiency (which is proportional to the peak counting rate) depends on the source-to-detector distance. Again, the agreement between the measurements and the calculations is found to be excellent. Fig. 3 shows the efficiency dependence on the source offset from the detector axis for the same distance along the axis. The agreement between the measurements and the calculations is excellent in this case as well.

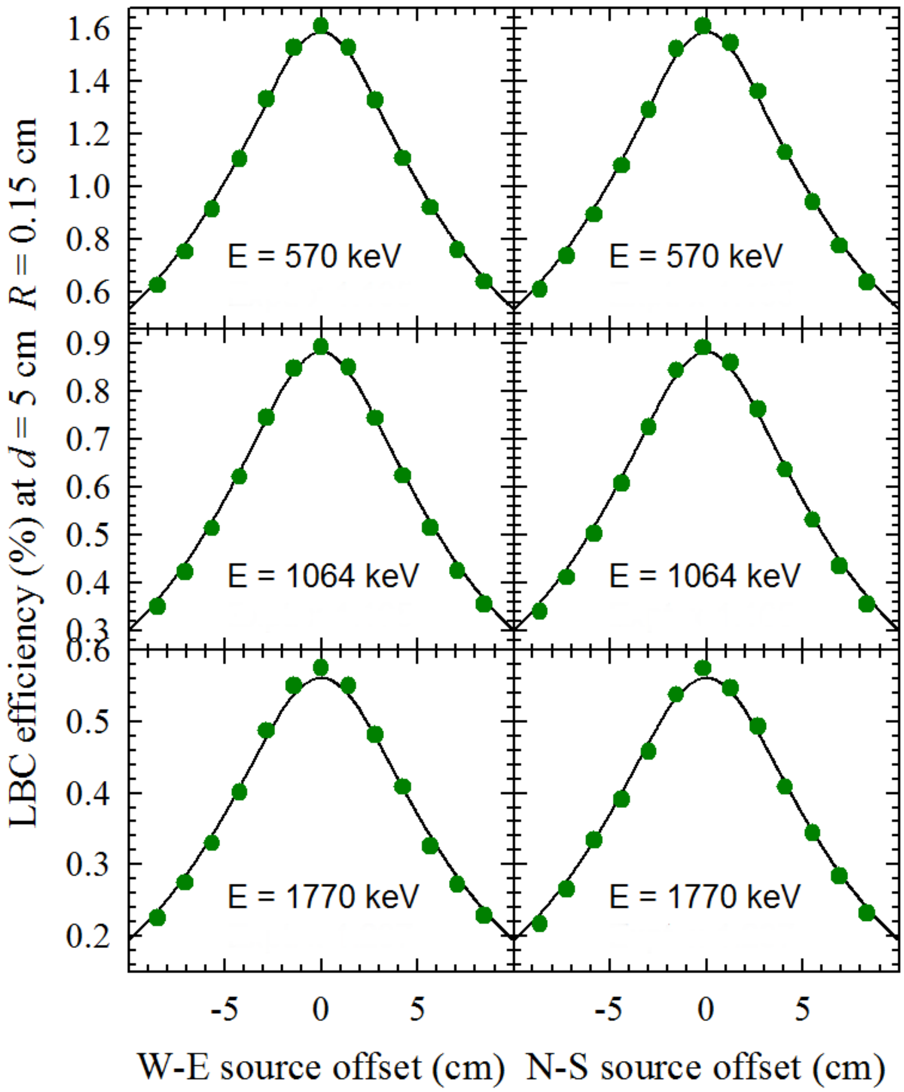

Fig. 3. Measured and calculated LBC detector efficiency as a function of source offset from the detector axis.

[1] https://www.berkeleynucleonics.com/lanthanum-bromochloride

[2] https://scionix.nl/high-resolution-lbc-scintillators/

[3] https://cyclotron.tamu.edu/see/

[4] https://www.berkeleynucleonics.com/bmca-ethernet

[5] https://www.berkeleynucleonics.com/basic-spectrometry-software

[6] https://www.berkeleynucleonics.com/bgamma-software-package

[7] J.A. Halbleib and T.A. Mehlhorn, Nucl. Sci. Eng. **92**, 338 (1986), J.A. Halbleib, R.P. Kensek, T.A. Mehlhorn, G.D. Valdez, S.M. Seltzer, and M.J. Berger, CYLTRAN 3.0, Sandia National Labs (Albuquerque, NM), Report SAND91-1634 (1992).

[8] https://www.gammadata.se/products/radiation-detection/radioactive-sources/beta-standards/conversion-electron-sources/