

The Evaluation of True Coincidence Summing Effect on CTBTO-type Sample Geometry

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Abstract

The CTBTO sample geometry is filter paper compressed to a 7 cm diameter disk counted directly on the endcap of a HPGe detector. This geometry has high efficiency, but the activity calculated from the spectrum is affected by true coincidence summing (TCS). TCS reduces the peak area for coincidence gamma rays, thus the calculated activity will be low unless TCS is accounted for. NIST-traceable standards were used to calibrate the detectors and measure the TCS effect for both the 5 mm and 15 mm thick disks. Results show the TCS impact on ^{134}Cs to make the reported activity about 25% low if the summing correction is not applied.

Introduction

The Comprehensive Test Ban Treaty Organization (CTBTO) monitors the atmosphere for radioactive materials in order to verify that there are no violations of the CTBT, that is, there is no illegal nuclear testing or processing by any organization. This is done by placing monitoring stations at many places around the world to detect certain nuclides associated with nuclear materials. The monitoring systems all pass large amounts of air through large filters to trap as much of the particulate as possible. The filters are then counted on a germanium detector and the resultant spectrum analyzed. The small amount of particulate distributed on the large filter is best counted by putting the filter as close to the detector as possible. There are two principle counting geometries used in the currently deployed systems. One geometry is a disk made from compressing the filter paper into a 70 mm by 5mm or a 70 mm by 15 mm disk and putting the disk directly on the endcap of the detector. The second geometry is to fold the filter into a rectangle about 8 cm by 24 cm and forming it into a cylinder around the detector, such that the principle active surface is the side of the detector. Typically the disk samples are counted on manual systems and the rectangular samples are counted on automatic stations. In addition to the monitoring stations, there are reference stations which verify the results from the monitoring stations. The reference stations count disk samples and the rectangular samples are compressed into disks for use in the reference stations. The detectors in the reference laboratories are low-background and placed in shields to reduce the background. The samples are counted for at least 24 hours.

True Coincidence Summing (TCS) occurs for nuclides which emit two or more gamma rays in coincidence, that is, the time between the emission of the two gamma rays is very short compared to the charge collection time in the germanium detector. A similar problem exists for the capture of X-rays in coincidence with the emitted gamma ray. This is grouped with the cascade gamma-ray summing. When the coincident gamma rays or X-rays are captured in the detector, the signal from the detector is the sum of both photons. This results in the loss of counts in the full energy peak for the gamma rays and an increase in counts in the spectrum background above the peaks as well as the appearance of peaks at the energy of the sum of the energies of the individual peaks. The loss of counts in the X-ray peak is not of concern. The most common example is ^{60}Co , where the 1173 keV and 1332 keV gamma rays sum to form the 2505 keV peak. The most common example of X-ray summing is ^{137}Cs , when detectors sensitive to the low-energy X-rays are used. The ^{241}Am gamma ray (59 keV) is of interest, so the detector must have some sensitivity to low energies, most stations satisfy the requirement with P-type detectors.

The decrease in the full energy peak counts means the efficiency for this nuclide is reduced from the expected efficiency at this energy. To obtain the correct activity for a summed nuclide, a correction must be applied to the peak area. The amount of summing depends on the detector-source geometry and on the nuclides. This makes the correction dependant on the individual gamma ray energy and nuclide, as well as the geometry. The CTBTO counting geometries are selected to maximize the efficiency, but this also maximizes the coincidence summing effect.

Earlier work described the TCS Correction (TCC) developed by Blaauw, et al^{1, 2, 3}, and implemented in GammaVision for the analysis of HPGe spectra in various geometries.⁴ In the Blaauw work, it is shown that the TCC can be reduced to knowing the full-energy peak efficiency, the total efficiency and the effect of extended or volume samples on the efficiency. In Ref. 4, it was shown that the correction to the activity ranged from 1.05 to 1.5 for ¹³⁴Cs on different sample geometries on a selected, large-efficiency detector.

This work concentrates on the TCC for the disk-type CTBTO sample geometries. Data were collected for the disk samples on the endcap of several detectors.

The dimensions are shown in Table I. These detectors are typical of the detectors currently in use in CTBTO stations and laboratories. The efficiency of one detector was well characterized in an earlier work.⁵ The diameter of this detector is larger than the sample diameter (70 mm), and about the optimum size for this sample⁶.

The detector-source geometry was calibrated using NIST-traceable sources for the simple mixture (²⁴¹Am, ¹⁰⁹Cd, ⁵⁷Co, ¹³⁹Ce, ²⁰³Hg, ¹¹³Sn, ¹³⁷Cs, ⁶⁰Co, ⁸⁸Y) and the TCC mixture (²⁴¹Am, ¹⁰⁹Cd, ⁵⁷Co, ¹³⁹Ce, ²⁰³Hg, ¹¹³Sn, ⁵⁴Mn, ⁶⁵Zn, ¹³⁴Cs, ¹³⁷Cs, ⁸⁸Y) for both thicknesses of sample. Note that ⁶⁰Co is not used in the TCC mixture, even though it is a TCS nuclide because of th interference with the single escape peak of ⁸⁸Y and a sum peak from ¹³⁴Cs. In the case of the simple mixture, the TCS for ⁶⁰Co and ⁸⁸Y is ignored in the efficiency calculation. The sources were made with water-equivalent epoxy, which is less absorbing than the glass fiber filters used by the CTBTO stations. No correction was made for the absorber in these results.

Detector Name	Type	Diameter x Length (mm)
P41239A	GEM FX	85 x 30
ACT II	BEGe	70 x 27

¹ Sjoerd J. Gelsema, "A three-curves approach for dealing with true coincidence summing effects in gamma-ray spectrometry of absorbing sources", Ph.D. Thesis (200), Technical University, Delft, The Netherlands.

² Menno Blaauw, "The use of sources emitting gamma-rays for determination of absolute efficiency curves of highly efficient Ge detectors," NIM A322, 1993, pp. 483-500

³ Menno. Blaauw, "The Accuracy of k-1-Standardized INAA Applied to a Gold-Lined Well-Type Detector", J.Radioanal.Nucl.Chem. 245 (2000) 185-188

⁴ Keyser, Ronald M., Haywood, Susan E., and Upp, Daniel L., "Performance of the True Coincidence Correction in Gamma Vision," Proceedings of the ANS Annual meeting, June 2001.

⁵ Ronald M. Keyser and Walter K. Hensley, "Efficiency of Germanium Detectors as a Function of Energy and Incident Geometry: Comparison of Measurements and Calculations", Proceedings of the MARC VI Conference, April 2003

⁶ R. M. Keyser, T. R. Twomey and P. Sangsingkeow, "Advances in HPGe Detectors For Real-World Applications," Journal of Radioanalytical and Nuclear Chemistry, Vol. 244, No. 3 (2000) 641-647.

Experimental Setup

The detectors were connected to a DSPEC jr or a digiDART for the signal processing and spectrum storage. Both of these are 16k-channel, DSP-type MCAs. The data were collected for at least 3600 seconds to obtain full energy and sum peaks with low counting uncertainty. The rise time (shaping time) was selected for each detector to get the best (minimum) resolution. In the worst case, the deadtime was about 35%.

Some of the spectra were collected with the detector in a low-background shield and some were collected in an open room. The sources were counted with the source directly on the endcap and centered on the diameter. For the downward-looking detectors, the source was fixed with tape and a mechanical support to ensure the source did not move during the count.

An example spectrum of the simple source is shown in Fig. 1 and the TCC mixture is shown in Fig. 2. The peak areas were calculated according to Eq (2) of IEC 61976⁷. This peak area calculation is based on the resolution of FWHM of the detector. In most spectra, the peak shape is close to Gaussian, making the peak area determination straight forward. In some cases, the peak had significant tailing, making the peak region harder to determine. Fig. 3 shows both types of peaks.

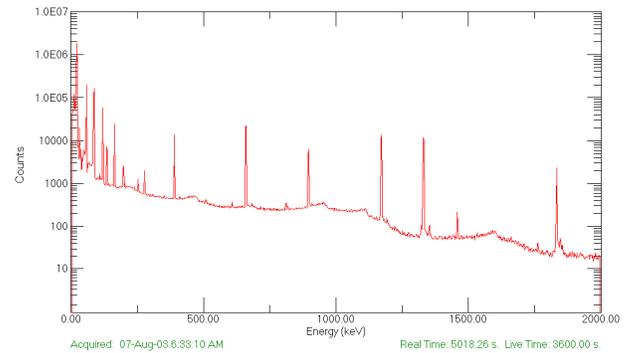


Figure 1. Simple Mixture 15 mm x 70 mm Disk on Endcap

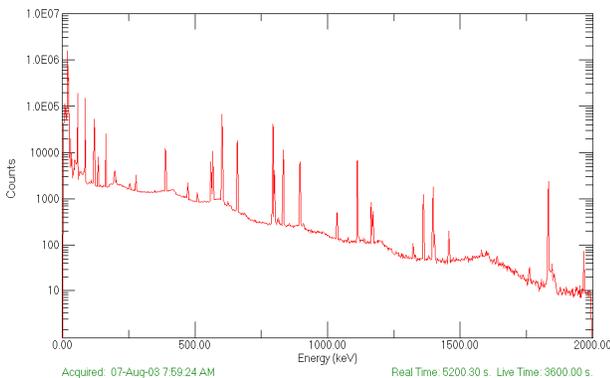


Figure 2. TCC Mixture 15 mm x 70 mm Disk on Endcap.

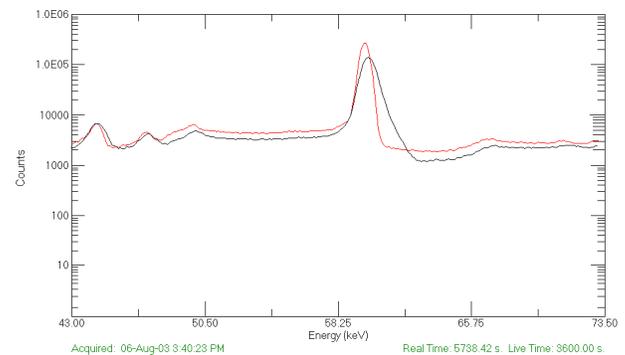


Figure 3. Comparison of Peak Shapes from Two Detectors

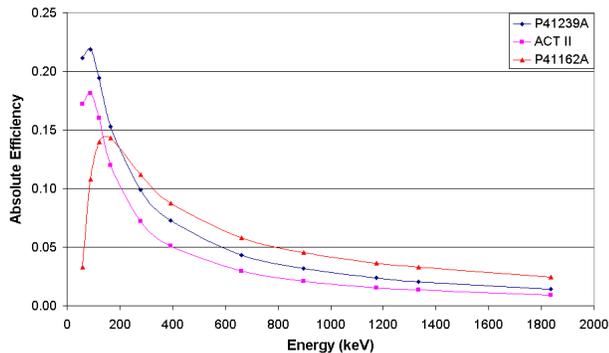


Figure 4. Efficiency vs Energy for all Detectors and 5 mm Disk.

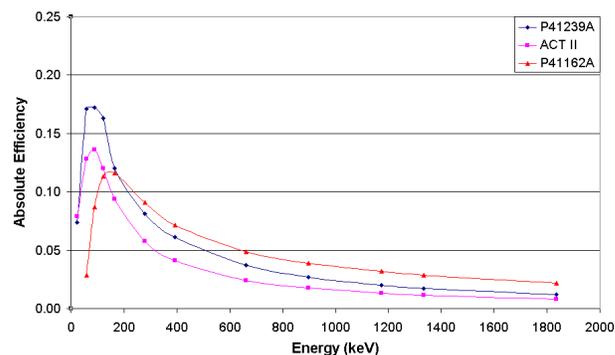


Figure 5. Efficiency vs Energy for All Three Detectors and the 15 mm Disk.

Efficiency

The efficiency for the simple mixture (5 x 70) for each detector was calculated in GammaVision using the polynomial fit for the big detector and the linear/quadratic fit for the thin detectors. Figure 4 shows efficiency plots: the larger the diameter, the more efficient at low energies and the longer the detector, the more efficient at high energies. The 15 x 70 mm disk shows similar plots as seen in Fig. 5. In this figure, the 22 keV efficiency has been estimated based on the measured vs expected ratio of the 22/88 keV energies from ^{109}Cd . Similar plots were obtained for the TCC mixture.

TCC Results

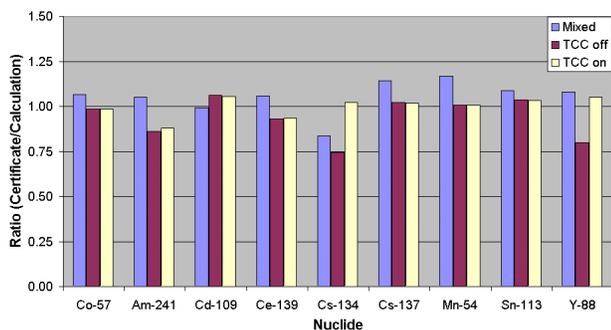


Figure 6. Ratio of Certificate to Calculated Value of 5 mm x 79 mm Disk for Different Analysis Options on P41162A.

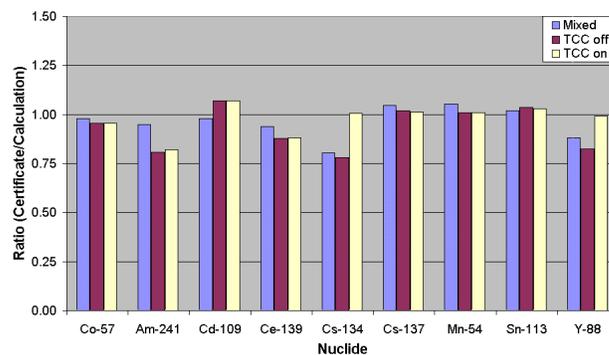


Figure 7. Ratio of Certificate to Calculated Value of 15 mm x 70 mm Disk for Different Analysis Options on P41162A.

The TCC mixture spectrum was analyzed using GammaVision in three ways: 1) calibration from simple mixture, 2) calibration from TCC mixture with TCC on, and 3) calibration from TCC mixture with TCC off. The simple mixture contains ^{60}Co and ^{88}Y which have summing gamma rays and contribute the 4 highest energy points to the efficiency curve. Consequently, the non-TCC fit to the data points gives a good fit to these points, but underestimates the ^{137}Cs point. This does, however, represent the usual situation when TCC is ignored. Figures 6 and 7 show the ratio of the activity calculated from the TCC mixture for the large P-type detector. Note that both ^{134}Cs and ^{137}Cs are improved by the TCC calibration and correction. ^{88}Y is also improved. The remainder of the nuclides except for ^{241}Am are essentially unchanged.

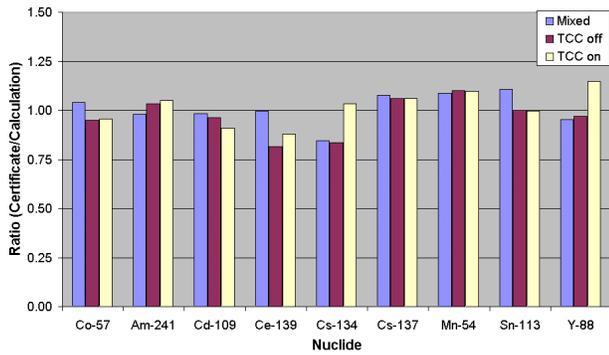


Figure 8. Ratio of Certificate to Calculated Value of 5 mm x 79 mm Disk for Different Analysis Options on ACT II.

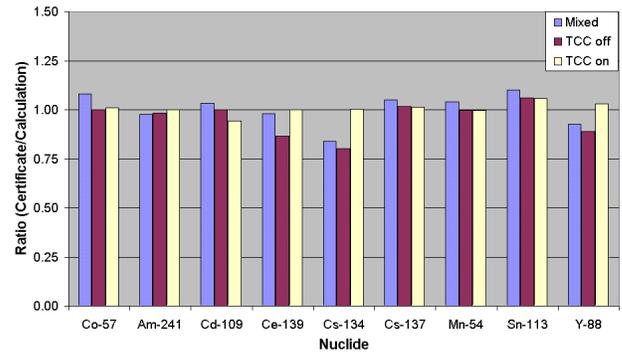


Figure 9. Ratio of Certificate to Calculated Value of 15 mm x 79 mm Disk for Different Analysis Options on ACT II.

Figures 8 and 9 show the same for the ACT II detector with similar results except for ^{139}Ce and ^{88}Y . The higher energy lines are reduced in intensity because of the thin detector accounting for the poor results for ^{88}Y .

Figures 10 and 11 show the same for the Profile X detector with similar results for ^{139}Ce and ^{88}Y .

Conclusions

Coincidence summing has been shown to have an impact of about 20 to 25% on the calculated activity of ^{134}Cs for the extended source geometries used by the CTBTO counting laboratories in typical detectors used in those laboratories. Coincidence summing effects were also seen in the results when calibrating using common nuclide mixture with ^{60}Co and ^{88}Y , for non-summing nuclides, such as ^{137}Cs . The TCC methods in GammaVision can be used to correct the analysis for the summing losses.

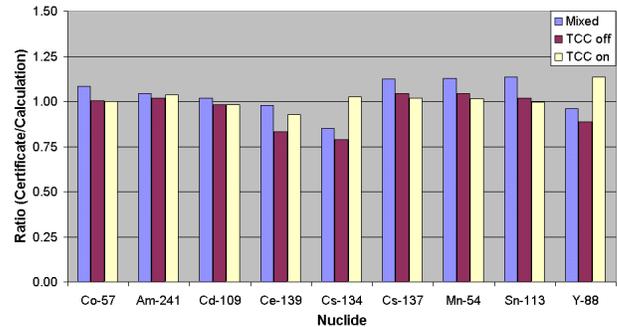


Figure 10. Ratio of Certificate to Calculated Value of 5 mm x 79 mm Disk for Different Analysis Options on P41239A.

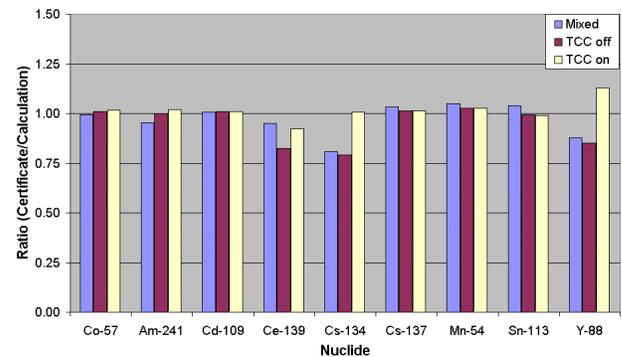


Figure 11. Ratio of Certificate to Calculated Value of 15 mm x 79 mm Disk for Different Analysis Options on P41239A.