Comparison of Triple-to-Double Coincidence Ratio Liquid Scintillation Counting Activity Determinations of ^{60}Co Using Field Programmable Gate Array and List-Mode Acquired Data

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TDCR Method

- Triple-to-Double Coincidence Ratio Liquid Scintillation Counting (TDCR LSC) = A primary method for the measurement of activity using ratio of triple-coincidence and double-coincidence count rates
- Allows an absolute measurement of the activity through a free-parameter efficiency
- Three-photomultiplier tube (PMT) system is used, with an LS vial containing activity and LS solution placed in the center
- Emitted scintillation light is collected by the PMTs
- Logic circuitry used to record the collected light as a triple coincidence or a double coincidence

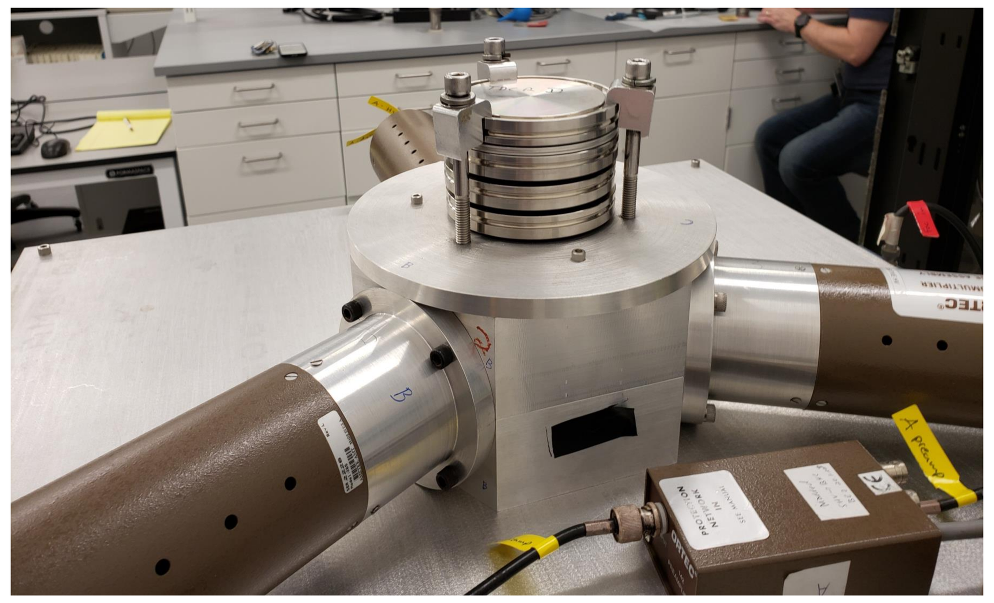

Figure 1. Photo of the TDCR LSC system used by the Radioactivity Group at NIST.

- Using various optical filters, the efficiency of light collection is alteredto provide a range of TDCR values
- Mathematical relationship between TDCR and activity (A):

$$TDCR = \frac{R_{Triples}}{R_{Doubles}} = \frac{\varepsilon_{Triples}}{\varepsilon_{Doubles}} \qquad A = \frac{R_{Doubles}}{\varepsilon_{Doubles}}$$

- $TDCR$, $R_{Triples}$, and $R_{Doubles}$ are experimentally measured, $\varepsilon_{Triples}$ and $\varepsilon_{Doubles}$ are determined using MICELLE2 models for efficiency as a function of TDCR value
- We studied the effects of different data acquisition methods, ^{60}Co beta spectrum used, and coincidence resolving time (CRT) on the resulting activity using the TDCR method

TDCR Efficiency Model

- MICELLE2 efficiencies are calculated from the energy spectrum and the energy-dependent quench function
- Three PMTs have equal quantum detection efficiencies
- Counting efficiency for triple coincidences:

$$\varepsilon_T = \int_0^{E_{max}} S(E)\left(1 - e^{\frac{-E\cdot Q(E)}{3\cdot M}}\right)^3 dE$$

- Counting efficiency for logical sum of double coincidences:

$$\varepsilon_D = \int_0^{E_{max}} S(E)\left(3\left(1 - e^{\frac{-E\cdot Q(E)}{3\cdot M}}\right)^2 - 2\left(1 - e^{\frac{-E\cdot Q(E)}{3\cdot M}}\right)^3\right) dE$$

- $S(E)$ is the beta spectrum expected to affect the efficiency, $Q(E)$ is energy dependent quench function, and M is the free parameter

Classical vs. BetaShape ^{60}Co Beta Spectra Study

- Explored the effect of using the classical ^{60}Co beta spectrum compared to the ^{60}Co beta spectrum calculated using BetaShape (BS)
- BetaShape: Developed by LNHB to improve decay data for beta and electron capture emissions using atomic screening and exchange corrections

Table 1

	Activity [Bq]	Uncertainty [Bq]	Comments
Classical Beta Spectrum	1268.5	2.4	Calculated uncertainty using the standard deviation of the mean for measured values from ^{60}Co Source 2 with no filter. Only Type A uncertainties considered, Type B uncertainties assumed to be constant across measurements.
BetaShape Spectrum	1266.5	2.4	

Table 1: Calculated activities of ^{60}Co using FPGA data (^{60}Co Source 2, no filter (Filter 0), CRT of 150 ns)

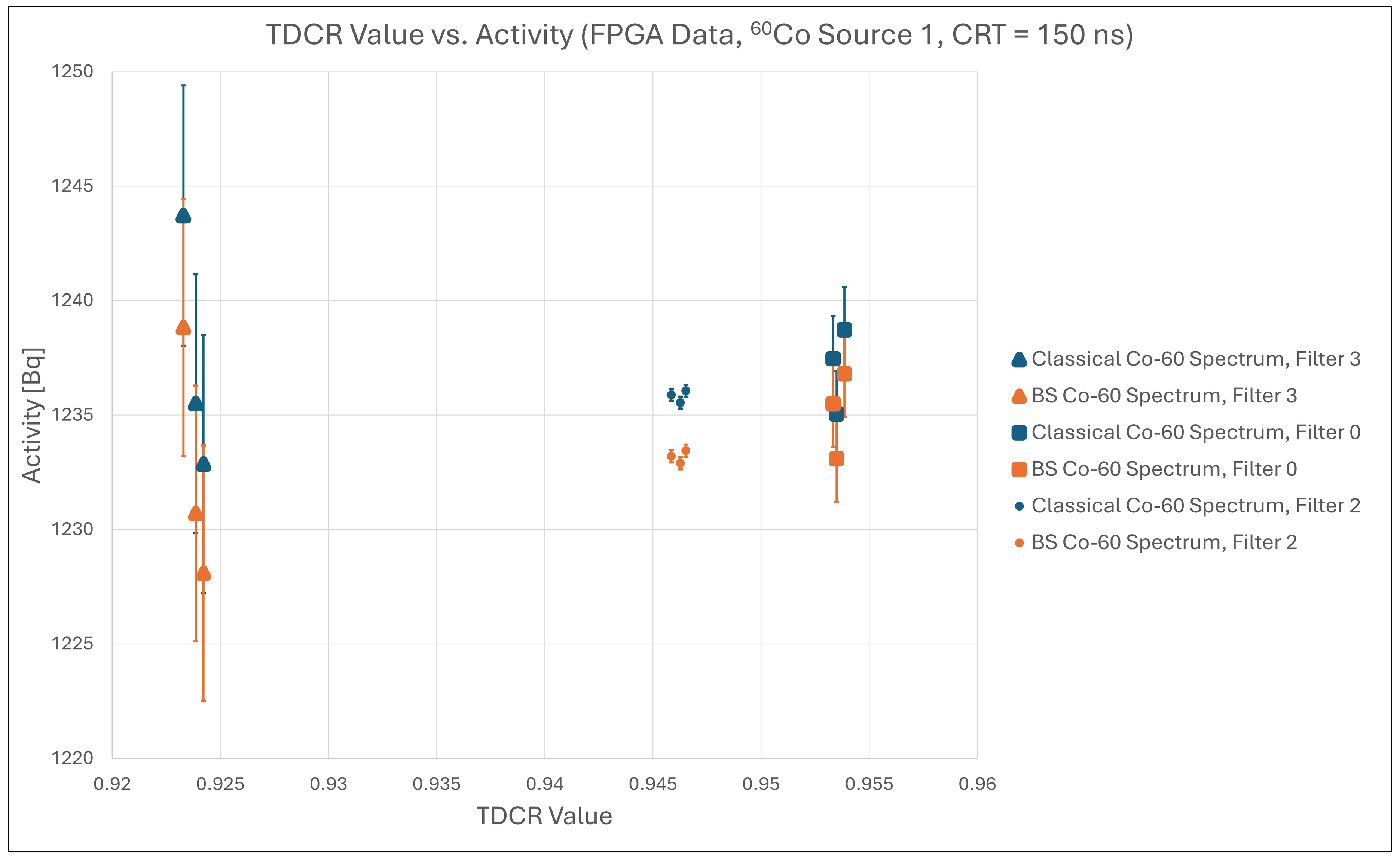

Figure 2: Calculated activity [Bq] as a function of the measured TDCR value calculated using FPGA acquired data for ^{60}Co Source 1 and a CRT of 150 ns with different filters applied

Coincidence Resolving Time Study

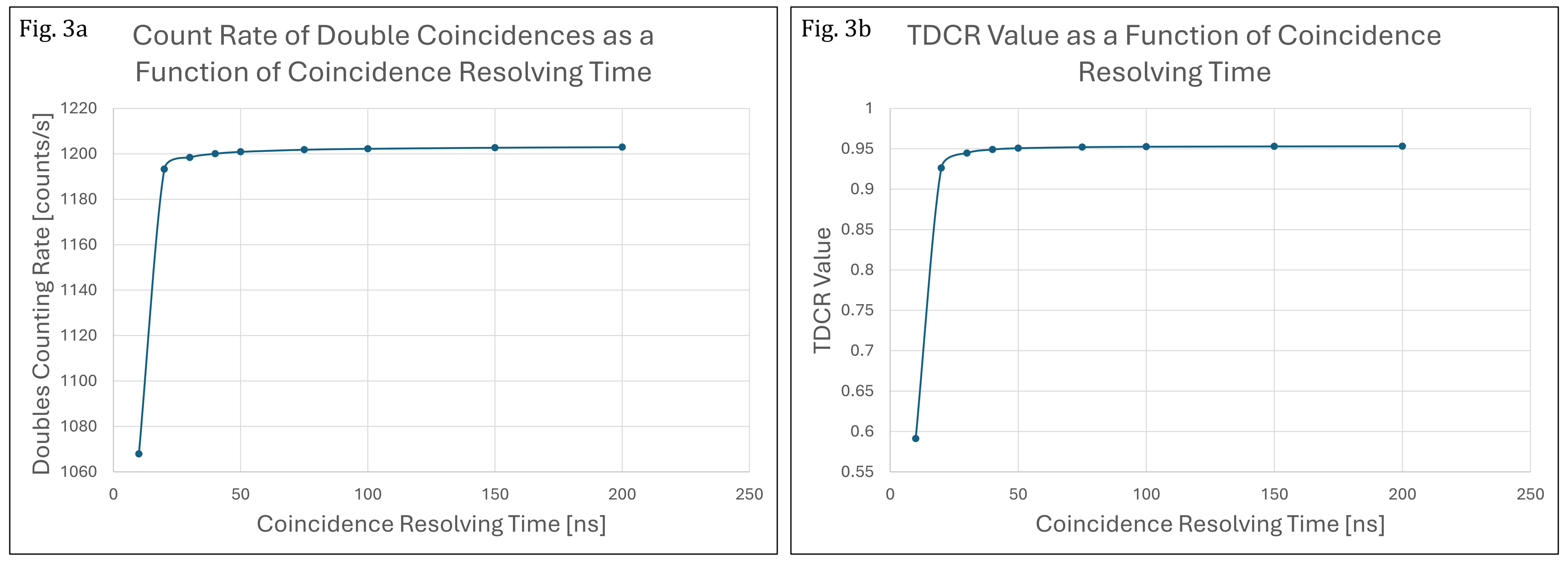

Figure 3: Effect of CRT on double coincidence counting rates (a) and TDCR values (b) done using list-mode data taken with ^{60}Co source 2 and Filter 0. Post-measurement data analysis available with list-mode data to change CRT and compare observed values.

FPGA vs. List-Mode Data Acquisition Study

- FPGA = Field Programmable Gate Array
  - Array of gates you can program, turning software into hardware
  - Does logic in real-time
  - Must make alterations to dead times and CRTs in real time while measurements are taken because they are hardware adjustments
- In the process of replacing FPGA system with Caen 5724 digitizer
- Collects list-mode data
  - Every measurement gets a timestamp and a peak height, all analysis is done after measurement
  - Can make alterations to lower discriminator level, extending dead time, and coincidence resolving time after physical measurement
    - In this work, only effects of changing CRT were explored

Table 2

	Activity [Bq]				Comments
	List-Mode Data	Uncertainty	FPGA Data	Uncertainty	
Classical Beta Spectrum	1266.5	3.1	1268.5	2.4	Calculated uncertainty using the standard deviation of the mean for measured values from ^{60}Co Source 2 with no filter and a CRT of 150 ns for both data sets. Only Type A uncertainties considered, Type B uncertainties assumed to be constant across measurements.
BetaShape Spectrum	1264.5	3.1	1266.5	2.4	

Table 2: Calculated activities of ^{60}Co using list-mode data and FPGA data, done using both the classical ^{60}Co beta spectrum and the BS ^{60}Co beta spectrum (^{60}Co Source 2 with no filter (Filter 0) and CRT of 150 ns)

Conclusions

- CRT of at least 50 ns needed to catch all true coincidences
- FGPA and list-mode acquired activity determinations are consistent within 0.16%, but list-mode data uncertainty is slightly larger than FPGA data uncertainty
- Improved beta spectrum does not reduce the efficiency-dependence of the calculated activities
  - Still see different activities with differences in efficiency

Acknowledgements

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References

[1] Kossert, Karsten & Marganiec-Gałązka, Justyna & Mougeot, Xavier & Nähle, Ole. (2017). Activity determination of 60 Co and the importance of its beta spectrum. Applied Radiation and Isotopes. 134. 10.1016/j.apradiso.2017.06.015.

[2] Mougeot, Xavier. (2017). BetaShape: A new code for improved analytical calculations of beta spectra. EPJ Web of Conferences. 146. 12015. 10.1051/epjconf/201714612015.

[3] Denis E. Bergeron, Jeffrey T. Cessna, Ryan P. Fitzgerald, Lizbeth Laureano-Pérez, Leticia Pibida, Brian E. Zimmerman, Primary standardization of 212Pb activity by liquid scintillation counting, Applied Radiation and Isotopes, Volume 190, 2022, 110473, ISSN 0969-8043, 10.1016/j.apradiso.2022.110473.

[4] Kossert, Karsten, et al. "Uncertainty determination for activity measurements by means of the TDCR method and the CIEMAT/NIST efficiency tracing technique." *Metrologia*, vol. 52, no. 3, 22 May 2015, https://doi.org/10.1088/0026-1394/52/3/s172.

[5] Dutsov, Chavdar, et al. "Evaluation of the accidental coincidence counting rates in TDCR counting." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 977, 11 Oct. 2020, p. 164292, https://doi.org/10.1016/j.nima.2020.164292.