Efficiency calibration of a high purity germanium detector for astatine-211 quantification

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Project Overview

This research aimed to improve the accuracy and reliability of activity quantification for astatine-211 (^{211}At), a promising alpha-emitting radioisotope for targeted cancer therapy. Accurate measurement of ^{211}At is critical due to its short half-life (7.2 hours) and high linear energy transfer, both of which make it effective for destroying micro-metastases with minimal damage to surrounding healthy tissue [1, 2].

The project focused on developing a robust and precise efficiency calibration methodology for a high-purity germanium (HPGe) gamma-ray detector used at the Texas A&M Cyclotron Institute.

Methodology

A multi-source calibration strategy was implemented to improve the accuracy of the HPGe detector's efficiency characterization for ^{211}At activity quantification. Four standardized gamma-emitting isotopes (^{152}Eu, ^{133}Ba, ^{137}Cs, and ^{54}Mn) were selected to provide well-distributed, high-intensity gamma lines across a broad energy range, especially near the 687 keV peak of ^{211}At.

The methodology involved:

- Collecting long-duration gamma spectra (about 24 hours) with and without T-Flex shielding, simulating real measurement conditions.
- Calculating absolute efficiency values using known source activities and emission intensities.
- Modeling energy-specific efficiency curves for low and high energy regions using logarithmic polynomial fits [3].
- Validating the models through cross-calibration between isotopes and comparing results to known activity values.
- Determining and applying attenuation correction factors (e.g., 0.629 for 661.7 keV) based on measurements with and without shielding.

Software tools including Genie 2000, Interspec, and ROOT were essential for spectrum processing, background subtraction, and nonlinear regression analysis. This approach ensured greater accuracy in activity calculations, particularly in the high-energy region relevant to ^{211}At, and accounted for measurement conditions like shielding attenuation.

The low energy and high energy efficiency calibration curve are shown in Figs. 1 and 2, respectively.

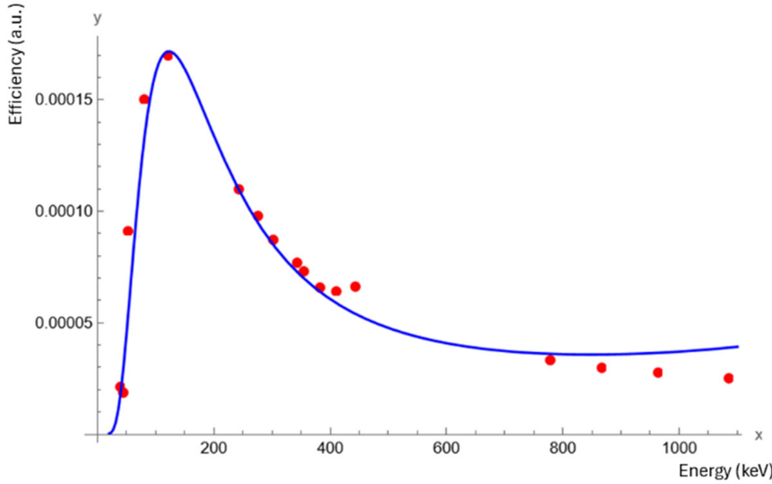

Fig. 1. Low energy efficiency calibration curve (higher energies left out of fit). The red dots are experimental data points, and the blue line is the fitted curve.

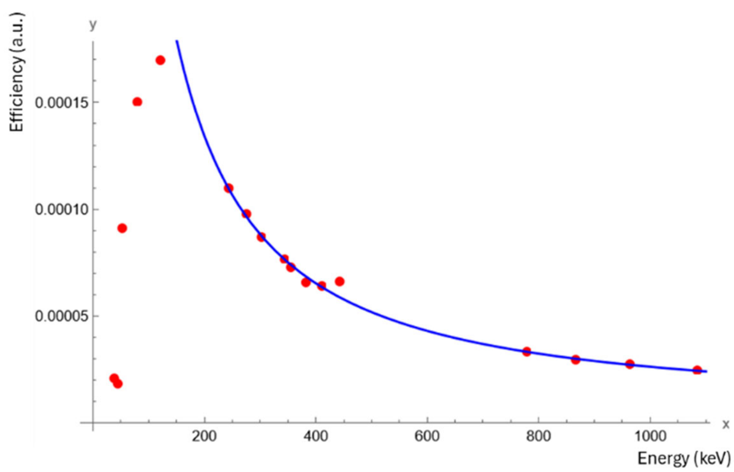

Fig. 2 High energy efficiency calibration curve (lower energies left out of fit). The red dots are experimental data points, and the blue line is the fitted curve.

Key Results

- **Dual Calibration Approach:** Separate efficiency calibration curves for low and high energy ranges were more accurate than a single full-range curve, particularly for the 687 keV peak of ^{211}At. The high energy model reduced error by nearly 50% compared to the full range.

- **Validation via Cross-Calibration:** Activities of known sources (^{152}Eu and ^{133}Ba) were accurately reproduced using each other's calibration curves, with percentage differences typically under 10%, affirming the method's robustness.
- **Attenuation Correction:** T-Flex shielding was shown to reduce detected gamma intensity by about 37%. Applying this attenuation factor led to a corrected ^{211}At activity of 65.2 μCi, closely matching the independently measured 60 μCi value from a dose calibrator.

Significance and Impact:

The methodology developed in this project enhances the reliability of ^{211}At activity quantification, addressing prior inconsistencies seen with single-source calibration models. By implementing energy-specific efficiency curves and incorporating shielding corrections, this work provides a validated framework for accurate detector calibration.

The results have implications not only for improved dosimetry in nuclear medicine but also for scaling production and ensuring safe clinical translation of 211At-based therapies. Furthermore, the calibration strategy can be extended to other isotopes and detection systems, making it a valuable contribution to the field of radiopharmaceutical development.

[1] P. Albertsson *et al.*, "Astatine-211 based radionuclide therapy: Current clinical trial landscape," Frontiers in Medicine **9** 1076210 (2023); doi: 10.3389/fmed.2022.1076210.

[2] Y.-S. Kim and M.W. Brechbiel, "An overview of targeted alpha therapy," Tumor Biology **33**, 573 (2011); doi: 10.1007/s13277-011-0286-y.

[3] I.A. Alnour *et al.*, "New approach for calibration the efficiency of HpGe detectors," AIP Conference Proceedings **1584**, 38 (2014); doi: 10.1063/1.4866101.