A Survey of Energy Resolution Reporting in the Nuclear Medicine Imaging Community

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Introduction

Energy resolution and photopeak position are two of the most important values provided when reporting energy performance of gamma ray detectors, such as for PET or SPECT. Each instrumentation research group implements its own approach for defining the photopeak region and extracting a measure of the centre location and full-width at half maximum (FWHM) energy resolution. It is then largely taken on faith that the result reported are accurately calculated.

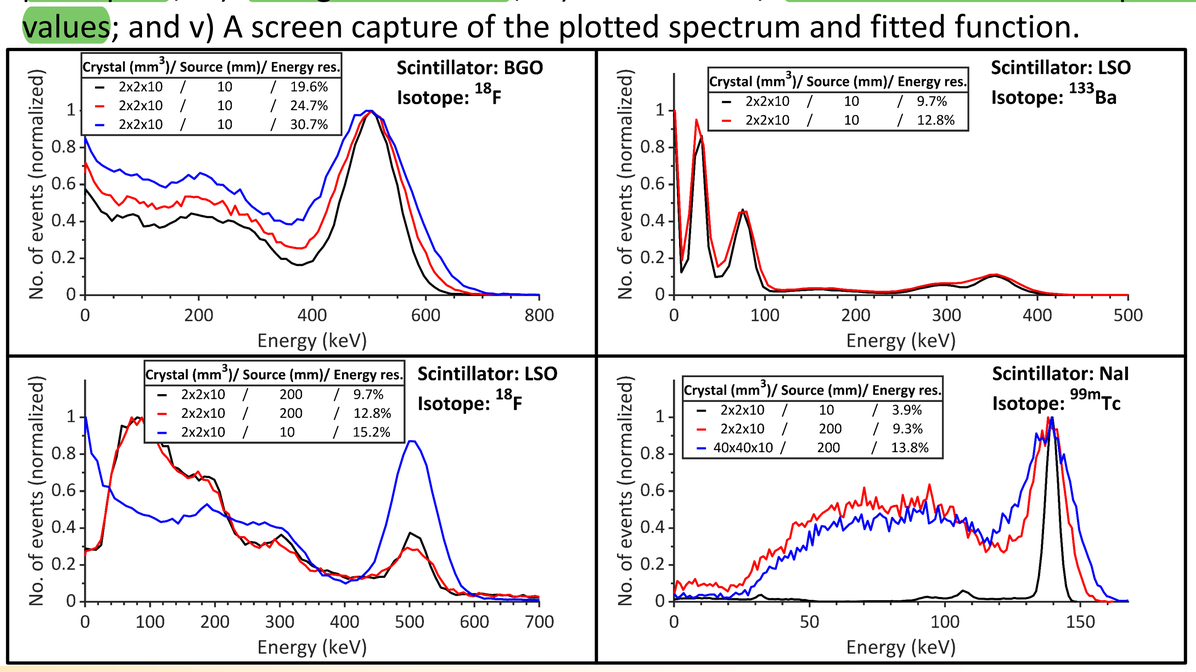
In this work we present the results of a survey of instrumentation groups in which a common set of data was sent to each group with a request to analyze the spectrum to determine the photopeak position and energy resolution.

Survey Data

- GATE v8 was used to generate sets of list-mode events for the isotopes, geometries, and detector configuration listed in the table below. All sources simulated were assumed to be isotopes uniformly distributed in a water sphere of the size listed.
- Event energy was taken as the sum of all 'hits' within the crystal for a given event and the event energy was blurred by GATE according to the FWHM energy resolution given for each case.
- No pileup or nonlinear energy detection effects were simulated.
- List mode files contained a total number of events ranging from 21,600 to 275,000.
- For each list mode data set, a random scalar value was applied to all events so that the photopeak was not centered at an obvious value (e.g. 511 keV or 140 keV).

Survey Participants

- 61 instrumentation research groups were contacted to participate in the survey.
- 19 completed responses were provided. Of these, one was excluded because the results were an obvious outlier due to the manner that results were calculated.
- Some groups provided more than one result using different fitting functions.
- Each participating group was sent the set of list mode files together with instructions to report for each spectrum: i) FWHM energy resolution; ii) Centre location of the photopeak; iii) Fitting model used; iv) If calculated, the uncertainties for reported values; and v) A screen capture of the plotted spectrum and fitted function.



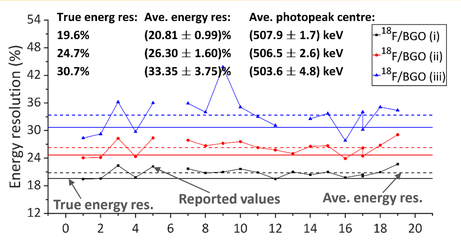
Results

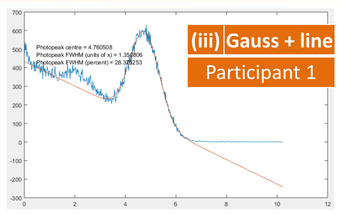
Fitting Function Used:

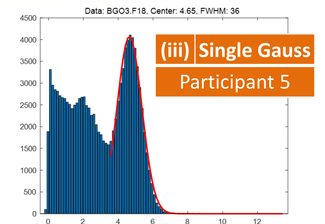
- For the ^{18}F spectra, the fitting methods used were: a) 10 cases fit with a single Gauss function; b) 5 fit with a Gauss plus line function; c) two fit with Gauss plus exponential function; d) one fit with Gauss plus line plus sigmoid curve; and e) one fit with Gauss curve to the peak with FWHM estimated as 2x the upper side width at half-maximum.
- For the ^{99m}Tc spectra, the fitting methods used were: a) 11 cases fit with a single Gauss function; b) 5 fit with a Gauss plus line function; c) two with a Gauss plus exponential function; d) one with a Gauss plus sigmoid function; e) one with a double Gauss curve; and f) one with a Gauss curve fit to the peak with FWHM estimated as 2x the upper side width at half-maximum.
- For the ^{133}Ba spectra, respondents were asked to fit the two overlapping photopeaks at 302 and 356 keV. The methods used were: a) 9 cases of fit with a double Gauss function; b) 4 cases using a double Gauss plus line function; c) two cases of a single Gauss curve fit to the segmented curve section for each photopeak independently; d) one case of a double Gauss plus line plus sigmoid function; and e) one case of a single Gauss plus line fit that treated both photopeaks as a single peak.

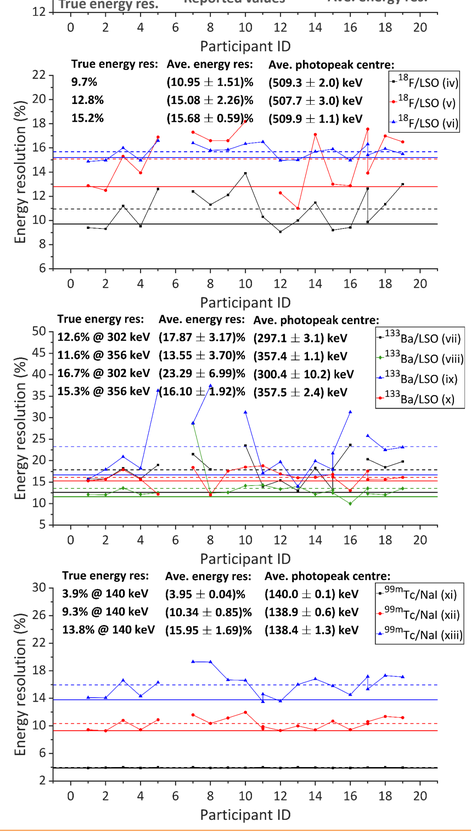
For analysis purposes, the reported values are grouped into two sets: a) Gauss only fits and b) Gauss plus offset function fits. The results are summarized in the table.

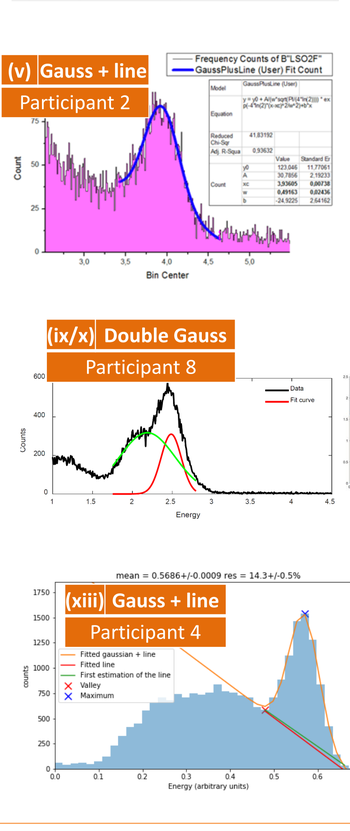
- On average, Gauss only fits tended to underestimated the photopeak centre value and overestimate the energy resolution. The most notable example of this is the BGO spectrum with 30.7% energy resolution, where the average reported value was 500.3 keV and 35.6% FWHM.
- Gauss plus offset functions more reliably returned values closer to the true values.
- Multipeaks fitting is further more challenging to return true values
- Deviation larger than 1% in the photopeak position are red highlighted, and larger than 10% in the energy resolution are orange highlighted.

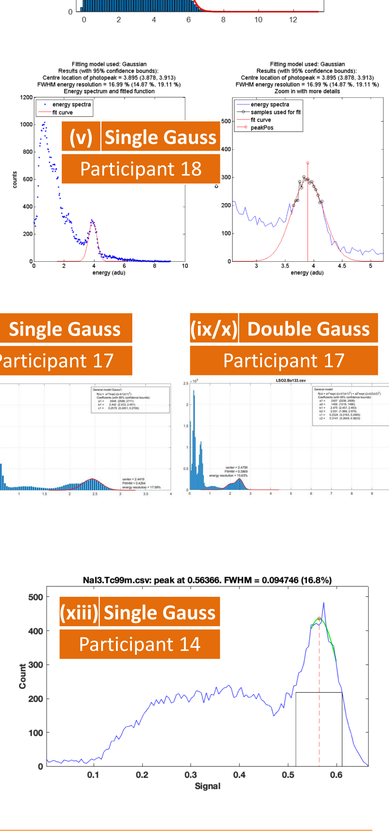












Red = Photopeak position error > 1%, Orange = Energy resolution error > 10%

Case ID	Isotope	Scintillator	Source Diameter (mm)	Crystal size (mm³)	Photopeak (keV)	True Values: Energy Resolution (% FWHM)	Gauss Only Fits: Photopeak Centre (keV)	Gauss Only Fits: Energy Resolution (% FWHM)	Gauss + Offset Fits: Photopeak Centre (keV)	Gauss + Offset Fits: Energy Resolution (% FWHM)
i	^{18}F	BGO	10	2×2×10	511	19.6	506.9±1.2	21.4±0.7	509.5±1.2	19.9±0.5
ii	^{18}F	BGO	10	2×2×10	511	24.7	500.3±1.8	27.4±0.9	508.8±1.7	24.8±0.9
iii	^{18}F	BGO	10	2×2×10	511	30.7	500.3±1.8	35.6±2.9	508.8±2.7	29.9±1.6
iv	^{18}F	LSO	200	2×2×10	511	9.7	507.9±0.8	12.1±1.1	510.8±1.7	9.7±0.7
v	^{18}F	LSO	200	2×2×10	511	12.8	505.6±1.2	16.9±0.8	509.9±2.6	13.3±1.7
vi	^{18}F	LSO	10	2×2×10	511	15.2	509.3±0.8	16.1±0.3	510.6±0.9	15.1±0.3
vii	^{133}Ba	LSO	10	2×2×10	302	12.6	296.8±2.6	17.9±3.3	298.1±3.9	17.4±3.2
viii					356	11.6	357.1±1.1	14.2±4.2	358.1±0.6	11.9±1.1
ix	^{133}Ba	LSO	10	2×2×10	302	16.7	301.7±11.3	24.6±7.8	298.7±9.1	20.4±5.5
x					356	15.3	357.3±3.1	16.2±2.3	357.9±0.7	15.4±1.3
xi	^{99m}Tc	NaI	10	2×2×10	140	3.9	140.0±0.1	3.9±0.1	140.0±0.1	3.9±0.1
xii	^{99m}Tc	NaI	200	2×2×10	140	9.3	138.7±0.5	10.9±0.6	139.2±0.1	9.6±0.4
xiii	^{99m}Tc	NaI	200	40×40×10	140	13.8	137.7±0.7	16.9±1.4	139.3±1.3	14.7±1.1

Conclusions

- Fitting functions that used a Gauss plus offset function were more reliable in estimating the true photopeak position and FWHM energy resolution.
- It is recommended that all groups incorporate a quality control check of this type to validate their software used for analysis and that this validation be mentioned in publications that report energy resolution values.

Acknowledgements

This work was supported by the Natural Science and Engineering Research Council of Canada Grant to ALG under Grant 341628. We thank all the survey respondents for their participation.

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