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A New Method for Analysing Daily Quality Control: Beta-Gamma Spectra for Checking Energy Calibration

VNIIA ROSATOM

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INTRODUCTION

The stability of the gain in beta-gamma coincidence detectors is of great importance for ensuring accurate measurements of radioxenon activity in the monitoring systems within the IMS.

METHODS/DATA

A comparison was made of the most popular methods for checking energy calibration for beta-gamma detectors:

- the horizontal slice method;
- the QC rotation method;
- fitting to a template.

START

RESULTS

The ‘template method’ was used to calculate the scale (‘tweaking’) factors for MIKS date. It showed an advantage over other approaches.

CONCLUSION

We recommend using the template method to control gain especially with poor QC statistics.

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Introduction

The stability of the gain in beta-gamma coincidence detectors is of great importance for ensuring accurate measurements of radioxenon activity in the monitoring systems within the IMS.

Gain drift can be caused, for example, by temperature instabilities and features of the detector electronics. Quality control (QC) sources with a known spectrum are usually used for gain control and, hence, energy calibration.

Energy calibration is performed by the gamma peak in the gamma spectrum of the QC source. Since there is no clear peak for the beta channel, various methods are used to calibrate the beta channel by processing the two-dimensional QC spectrum of beta-gamma coincidences. A significant problem for the correct estimation of beta gain consists in the poor statistics of the Compton scattering line.

The most popular methods for controlling the slope of the ^{137}Cs Compton line (E_b+E_g = 662 keV) for checking beta-energy calibration:

- the horizontal slice method;
- the QC rotation method;
- fitting to a template.

Here we will take a closer look at the new 2D template method used in the MIKS system.

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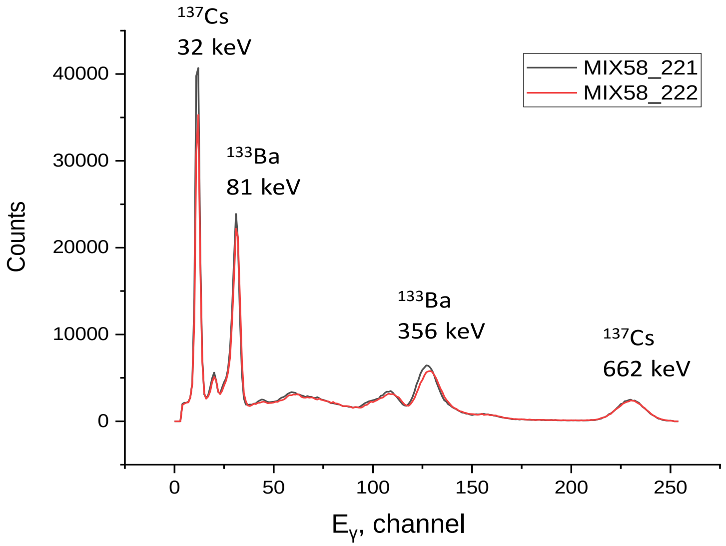
Methods/data

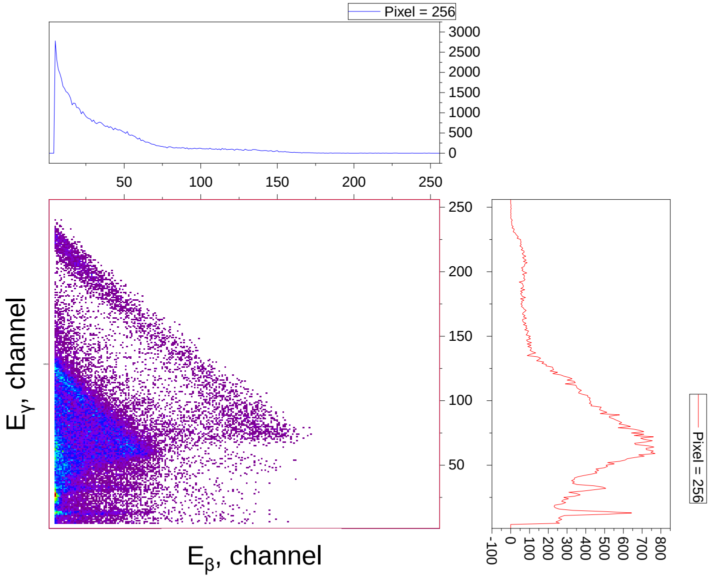
Detectors (NaI + plastic cell) in the MIKS rack (the lead shield was partially removed)

Plexiglas QC sources (^{133}Ba + ^{137}Cs)

Gamma spectrum



Beta-gamma spectrum



Acquisition is performed automatically using the QC source of the MIKS (^{133}Ba + ^{137}Cs). The procedure of daily QC measurement allows you to control the calibration of the scales of amplitude analyzers of gamma and beta channels. When the gain drift exceeds the permissible limits, the software issues a notification about the need to adjust the bias voltage of the detectors.

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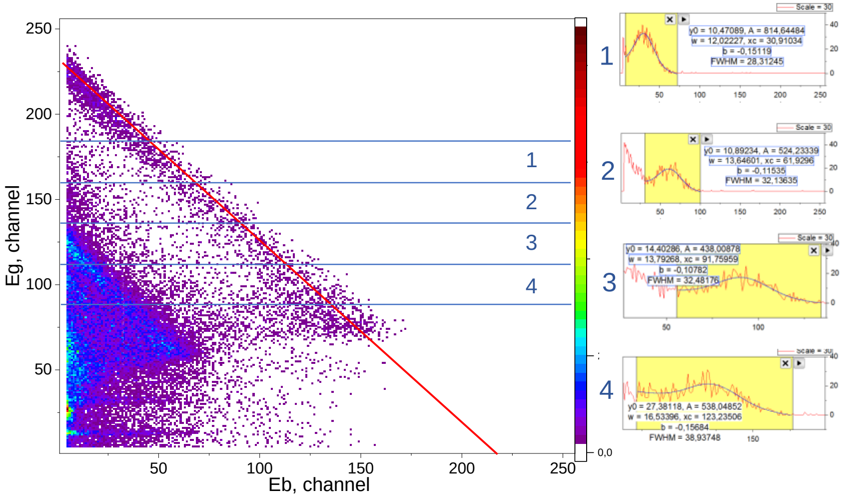
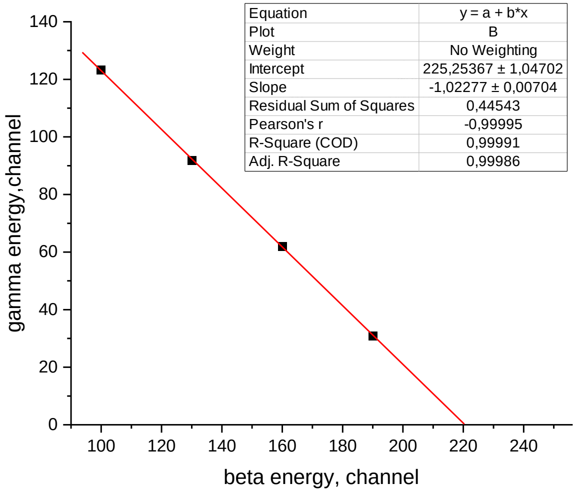
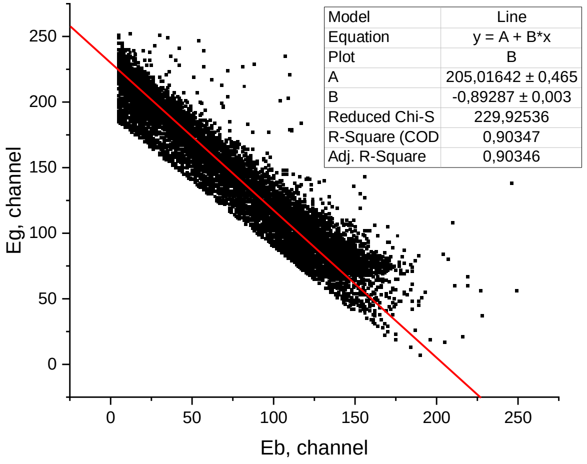
Compton line can be used to control the beta gain

Horizontal slice method





Linear regression (LS with horizontal errors)



- The horizontal slicing method is similar to the regression which minimizes the variance of **weighted horizontal errors**.
- You can use the whole spectrum without slices, and regression is carried out for spectrum points; however, this method is unstable.
- This method is scale-invariant because the slope is $\hat{\beta} = r\,\sigma_g / \sigma_b$

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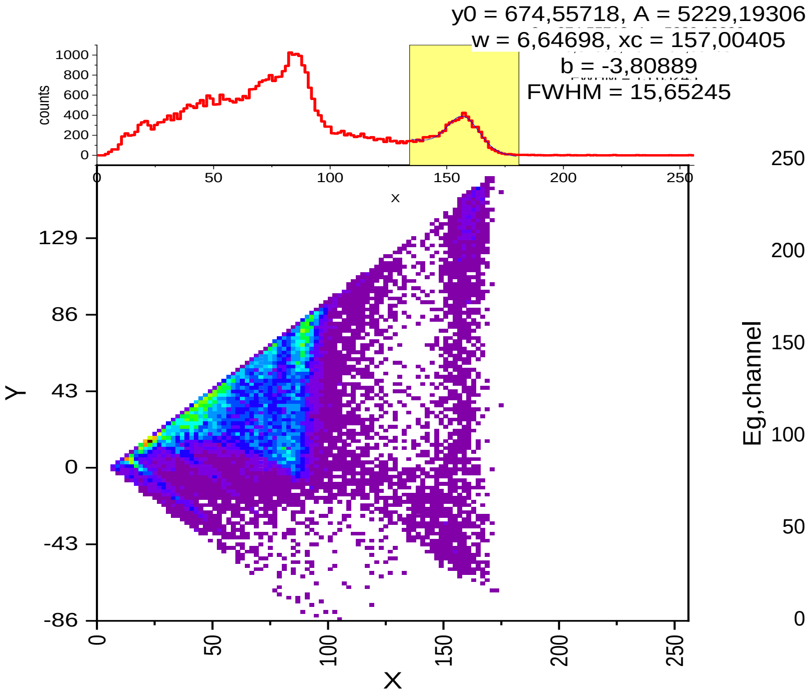
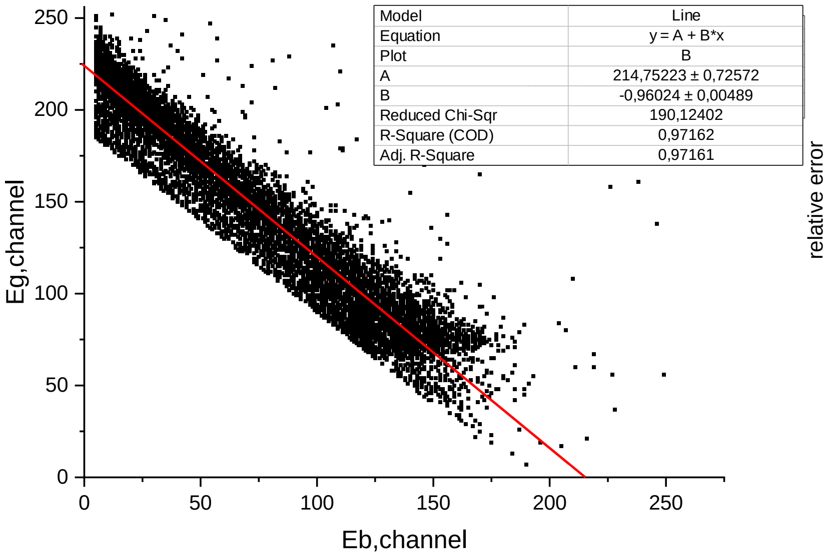
Rotation method and orthogonal regression

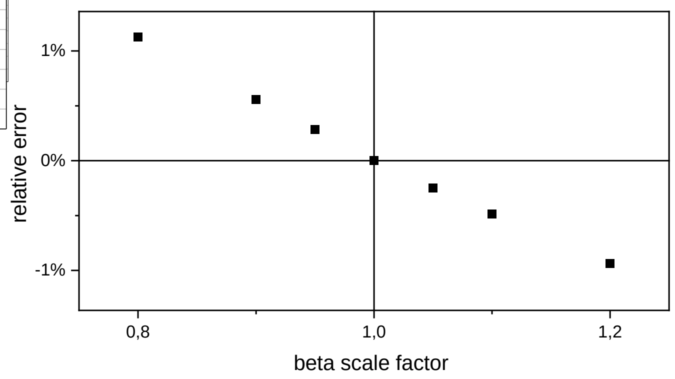


Orthogonal regression



Model	Line
Equation	y = A + B*x
Plot	B
A	214,75223 ± 0,72572
B	-0,96024 ± 0,00489
Reduced Chi-Sqr	190,12402
R-Square (COD)	0,97162
Adj. R-Square	0,97161

Relative error in estimator of the beta scale factor



- QC rotation method demands to rotate the reference frame to reach a minimum peak FWHM.
- The QC rotation method is similar to **orthogonal regression.** The regression line minimizes the sum of squared perpendicular distances from the data points to the regression line.
- This method is not scale-invariant, but it does matter when the gain shift is very large.

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Fitting to a template

The gain shift is a scale transformation. For a two-dimensional template spectrum $f(E_\beta, E_\gamma)$, it is determined by the following function:

$$\tilde{f}_{ab}(E_\beta, E_\gamma) = k\frac{1}{ab} f(\frac{E_\beta}{a}, \frac{E_\gamma}{b})$$

where $\tilde{f}_{ab}$ is the QC daily spectrum, the free parameters a and b are the scaling factors for gamma and beta, k is the fixed global scaling factor that accounts for different live acquisition times.

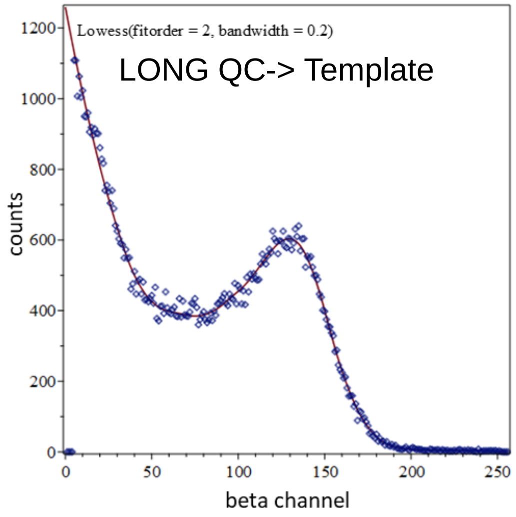
To create a template $f(E_\beta, E_\gamma)$, it is necessary to use the LONG QC spectrum histogram with long acquisition time. Daily fitting of the template to the QC spectrum using the weighted least squares method gives the scaling factors a and b of the gain shift.

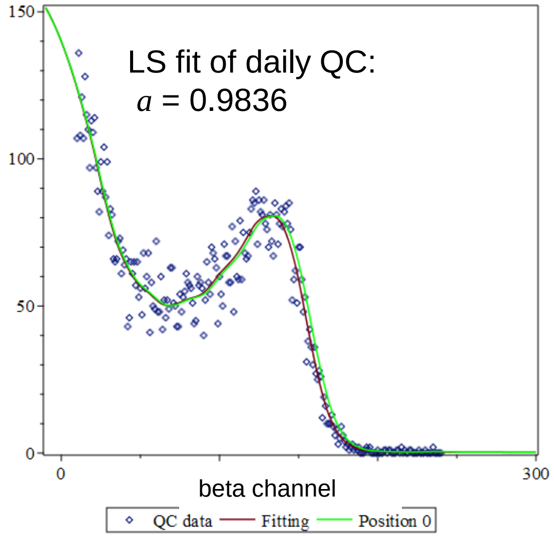
Total beta spectrum or beta spectrum projection can be used for template fitting. In this case, the gamma gain drift is determined by the standard approach (position of the 662 keV peak).

Here we will also consider a two-dimensional template for gain control.

Methods/data

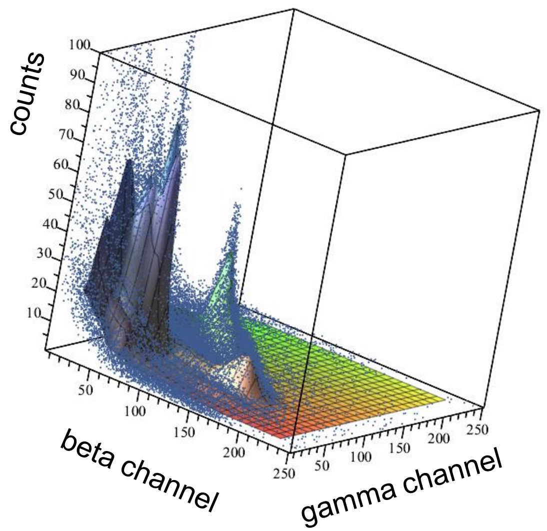
LS fitting to one-dimensional template of the beta spectrum projection (^{137}Cs only)



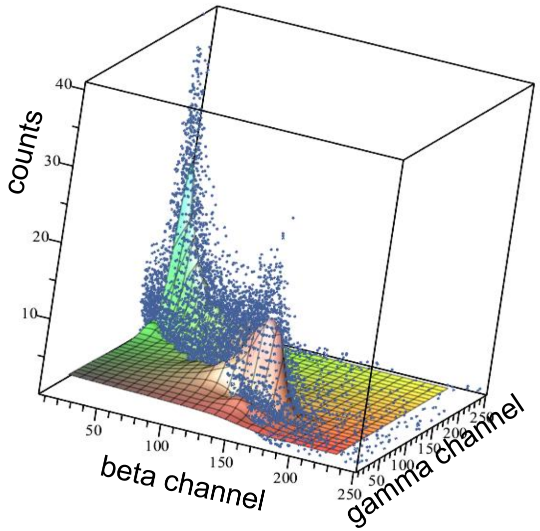


LS fitting to two-dimensional template

^{137}Cs + ^{133}Ba spectrum



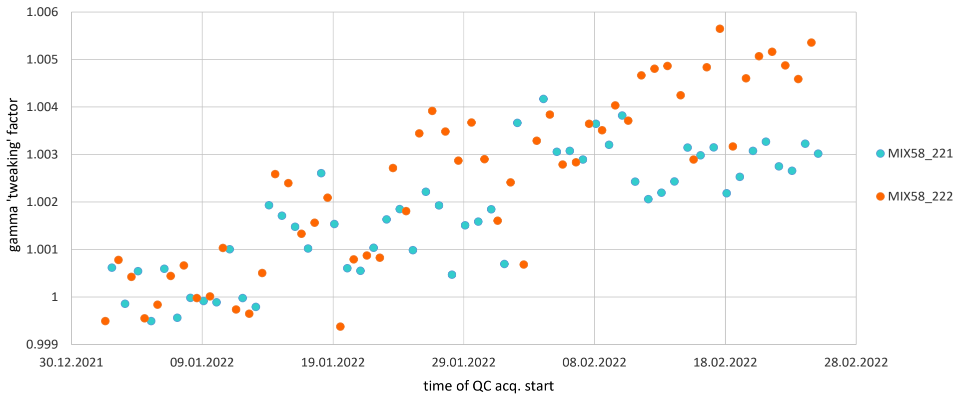
^{137}Cs spectrum



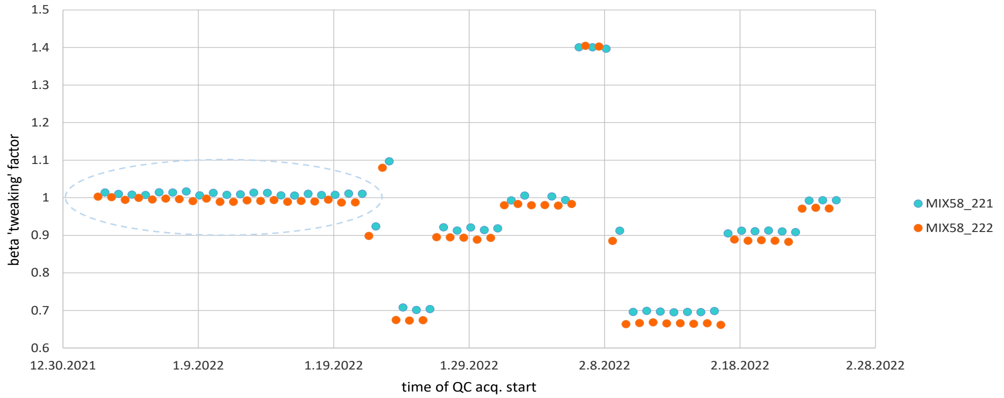
To create a template, it is necessary to smooth out the LONG QC spectrum histogram. The template is created using locally weighted scatterplot smoothing (LOWESS) of LONG QC spectrum (the duration of the LONG QC spectrum acquisition can be, for example, 24 h).

Results

Gamma

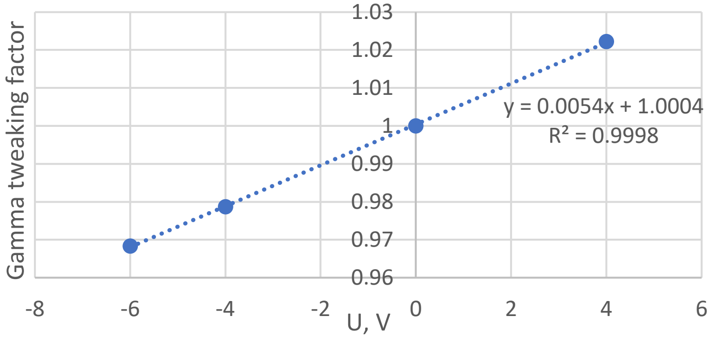


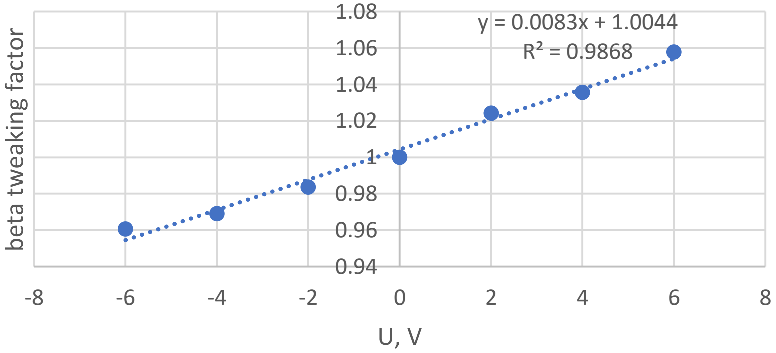
Beta



Standard QC spectra from MIKS for the period 01.01.2022-26.02.2022 were used. The ‘template method’ was used to calculate the scale (‘tweaking’) factors. Figures show examples of detector energy calibration drift. The bias voltage of the gamma detector was not changed, but bias voltage of the beta detector was changed manually to test the algorithm.

Scale coefficients vs. the bias voltage changes at the MIKS detectors





Conclusion

The method of 1D or 2D template fitting to the measured spectrum using the LS method is mathematically correct and provides more accurate gain shift estimates for QC spectra compared to the standard "horizontal slice" or rotation methods. The efficiency of template fitting approaches the maximum likelihood method and surpasses regression methods.

The "horizontal slice" method is equivalent to constructing some regression that determines the slope based on standard deviation ratios, which makes this method not robust in case of poor statistics.

The template method shows good robustness of fit even for poor statistics and can be used in everyday data processing.

The scaling factor estimates obtained by the template fitting method can be used to adjust the energy calibration:

- changes in the energy-to-channel ratio can be applied to the boundaries of the regions of interest (ROIs) corresponding to the original calibration;
- changes in the gain shift can be corrected immediately after the QC measurement by changing the bias voltage.