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CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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A Calibration Procedure of Beta-Gamma Coincidence Measurements in the International Monitoring System Network Using four Radioxenon Spikes

CTBTO PREPARATORY COMMISSION

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INTRODUCTION

A calibration method is developed for IMS noble gas systems monitoring the CTBT-relevant xenon.

METHODS/DATA

βγ coincidence systems with 4π geometry are calibrated by spikes ^{133}Xe, ^{133m}Xe, ^{131m}Xe and ^{135}Xe.

START

RESULTS

Efficiencies are determined by β, γ and βγ coincidence measurements without reference values.

CONCLUSION

The calibration results can be used to the net count calculation and regression analysis methods.

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Summary

- The current calibration procedure of beta-gamma coincidence analysis at the IDC is based on two spikes of Xe-131m and Xe-133 in addition of Monte-Carlo simulations for Xe-135.
- Purposes to develop a calibration procedure using four spikes at the IDC are:
  - To understand calibration procedures of different noble gas systems;
  - To perform efficiency calibrations consistently between different systems and analysis methods such as the net count calculation and regression analysis.

- The efficiency calibration is based on peak areas fitted in the spectra of beta and gamma singles, and beta-gamma coincidences.
- The efficiency of 30 keV X-rays, estimated by the Xe-131m spike measurement, is the same for all xenon isotopes for the peak fitting method.
- Gamma efficiencies of the NCC method are derived using the efficiency of 30 keV in gamma singles corrected by differences between net numbers of counts in ROIs and fitted peak areas.
- Beta efficiencies for each decay path are estimated using the gamma projection and gamma singles.

"A calibration procedure for beta-gamma coincidence detector-systems using four radioxenon spikes". (Applied Radiation and Isotopes in submission)

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Objectives

A efficiency calibration of beta-gamma coincidence detector-system is to determine detection efficiencies of each radioxenon and interferences between isotopes.

- Net numbers of counts estimated by the NCC method.
  - Square responding matrix $\boldsymbol{R}$ (5 ROIs by 5 isotopes)
  - Variance matrix: $\boldsymbol{C}-\boldsymbol{B}$; $\boldsymbol{V_{CB}} = [\boldsymbol{C}+\boldsymbol{V_B}] \cdot \boldsymbol{I}$
  - $\boldsymbol{X} = \boldsymbol{R}^{-1} \cdot (\boldsymbol{C}-\boldsymbol{B})$; $\boldsymbol{V_x} = \boldsymbol{R}^{-1} \cdot \boldsymbol{V_{CB}} \cdot [\boldsymbol{R}^{-1}]^T$

- Optimization analysis with least squares fitting
  - Deconvolution of X-ray contributions
    - $\boldsymbol{R}$: 6 ROIs by 5 isotopes
  - Optimization procedure using weighted least squares
    - ✓ Input: $\boldsymbol{C}-\boldsymbol{B}$; $\boldsymbol{V_{CB}}$; $\mathbf{W} = \boldsymbol{V_{CB}^{-1}}$; $\boldsymbol{R}$
    - ✓ $\boldsymbol{X} = \boldsymbol{V_x} \cdot \boldsymbol{R}^T \cdot \boldsymbol{V_{CB}^{-1}} \cdot (\boldsymbol{C}-\boldsymbol{B})$; $\boldsymbol{V_x} = [\boldsymbol{R}^T \cdot \boldsymbol{V_{CB}^{-1}} \cdot \boldsymbol{R}]^{-1}$
    - ✓ Output: $\boldsymbol{X}$ and $\boldsymbol{V_x}$ (Co-Variance matrix 5x5)

Matrix of interference corrections

	Radon	Xe135	Xe133	Xe133m	Xe131m
ROI-1	1	0	0	0	0
ROI-2	0.4848	1	0	0	0
ROI-3	0.3771	0.0112	1	0	0
ROI-6	0.0210	0.0121	0.2479	1	0.025
ROI-5	0.0206	0.0053	0.4051	0.025	1
ROI-4	0.1047	0.0442	1.2035	1.0526	1.0526

Efficiency of beta-gamma coincidence:

$$a_j = \frac{x_j}{\varepsilon_j \cdot BR_j} \frac{\lambda_j}{1 - e^{-\lambda_j \cdot T_A}} \frac{T_A}{T_{A_l}}$$

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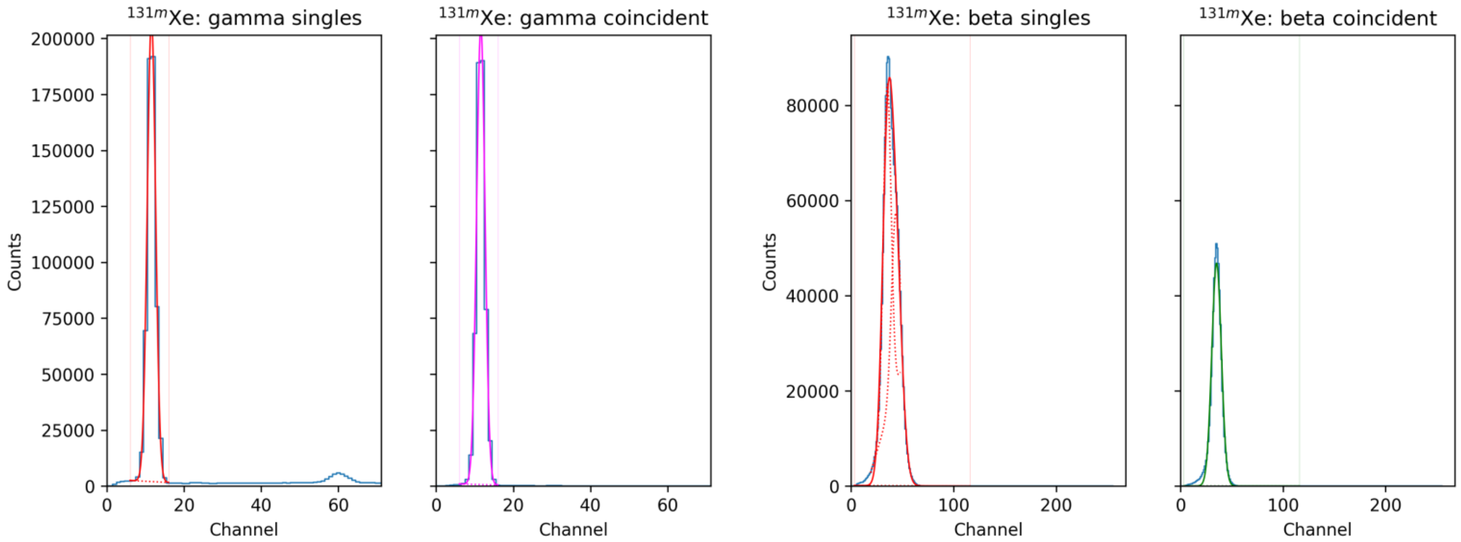
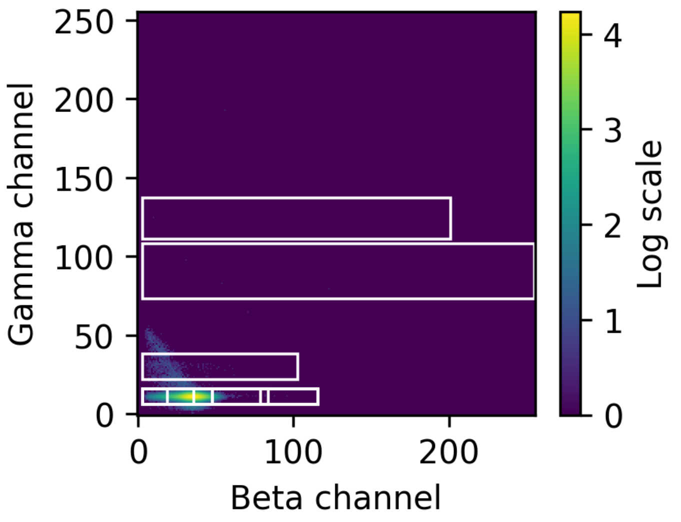
Methods

- Spikes of Xe-131m, Xe-133m, Xe133 and Xe-135 are used.
  - Pure radioxenon spikes
  - Beta-gamma coincidences, beta singles and gamma singles.
- Efficiencies are estimated without reference activity values.
  - A 4π detector geometry results in $\varepsilon_{bg} = \varepsilon_b \varepsilon_g$.
  - $N = \frac{c_g}{BR_g \varepsilon_g} = \frac{c_b}{BR_b \varepsilon_b} = \frac{c_{bg}}{BR_{bg} \varepsilon_{bg}}$

Beta and gamma efficiencies of Xe-131m

- $\varepsilon_{CE129} = \frac{c_{CE129x}}{c_{x(131m)}}$
- $\varepsilon_x = \frac{c_{CE129x}(BR_{CE159} + BR_{CE129})}{c_{CE(131m)} BR_{x(131m)}}$





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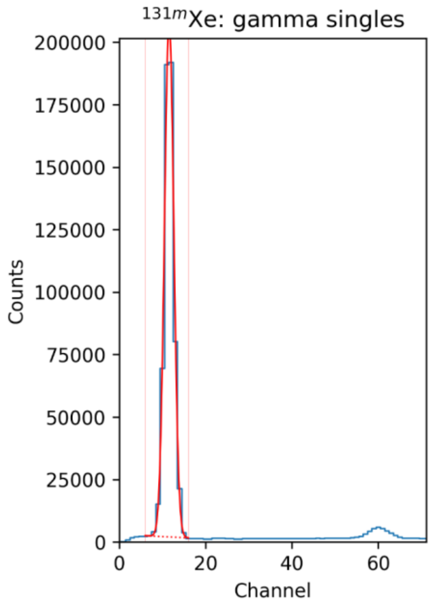
Features

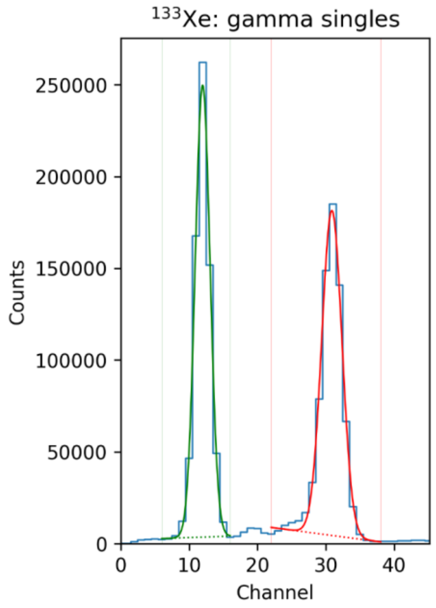
Gamma efficiencies are estimated by peak areas fitted in gamma singles.

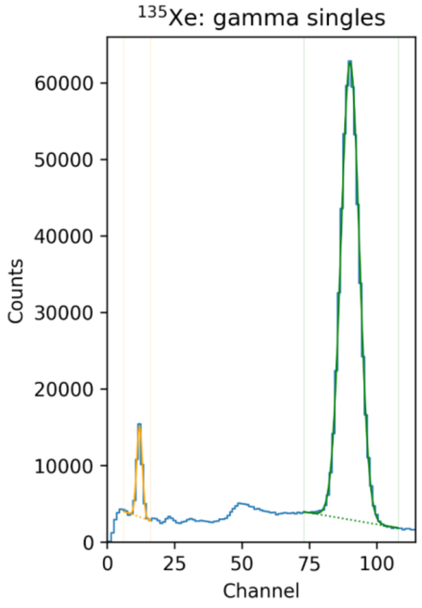
- 30 keV: ε_x is the same for each xenon
- 81 keV: $$\varepsilon_{g81} = \frac{BR_{x(133)}}{BR_{g81}} \frac{c_{g81}}{c_{x(133)}} \varepsilon_x$$
- 250 keV: $$\varepsilon_{g250} = \frac{BR_{x(135)}}{BR_{g250}} \frac{c_{g250}}{c_{x(135)}} \varepsilon_x$$

Efficiency of 30 keV X-rays using the gamma projection and beta singles

- $$\varepsilon_x = \frac{c_{CE129x}(BR_{CE159}+BR_{CE129})}{c_{CE(131m)} BR_{x(131m)}}$$
- This efficiency is a fundamental data point, which is subsequently applied to other isotopes.







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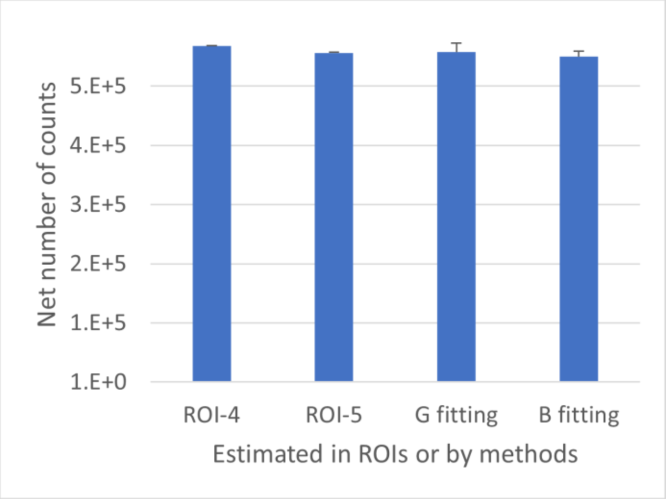
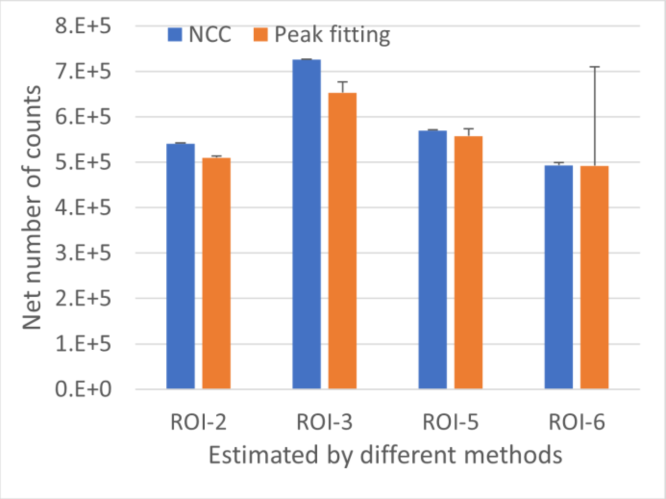
Results

Gamma efficiencies related to ROIs are derived from peak fitting.

- 30 keV for Xe-131m: $\varepsilon_{x(131m)}(NCC) = \frac{c_{x(131m)}(NCC)}{c_{x(131m)}(fitting)} \varepsilon_x$
- 30 keV for Xe-133m: $\varepsilon_{x(133m)}(NCC) = \frac{c_{x(133m)}(NCC)}{c_{x(133m)}(fitting)} \varepsilon_x$
- 81 keV: $\varepsilon_{g81}(NCC) = \frac{BR_{x(133)}}{BR_{g81}} \frac{c_{g81}(NCC)}{c_{x(133)}(fitting)} \varepsilon_x$
- 250 keV: $\varepsilon_{g250}(NCC) = \frac{BR_{x(135)}}{BR_{g250}} \frac{c_{g250}(NCC)}{c_{x(135)}(fitting)} \varepsilon_x$





Gamma efficiencies at 30 keV are different between Xe-131m and Xe-133m.

- $\varepsilon_x = \frac{c_{CE129x}(BR_{CE159}+BR_{CE129})}{c_{CE(131m)}BR_{x(131m)}}$ is dependent on the ROI-5 beta range.
- The fraction of ROI-5 over the peak range is different from the one for ROI-6.

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