Monte-Carlo-Informed Shape Learning for Gain Shift Correction based on $LaBr_3$:Ce,Sr Intrinsic Activitiy

innoRIID / AMETEK
RADIOISOTOPE IDENTIFICATION DEVICES

Felix Diel[1], Patrick Eulgem[2] and Marcus J. Neuer[1,3], *Member, IEEE*

[1]innoRIID / Ametek, Department for Research and Development, Merowinger Platz 1, 40225 Duesseldorf, Germany
[2] ORTEC / Ametek, Rudolf-Diesel Str. 16, 40670 Meerbusch, Germany
[3] RWTH Aachen University, Turm Str. 46, 52064 Aachen

IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS-MIC), Tampa, FL, US, 2024

Scan for PDF:

1 Introduction

1.1 Motivation

Lanthanum Bromide $LaBr_3$:Ce,La [1] manifested itself as a scintillation material of choice [2], [3], [4], if it comes to high resolution and good sensitivity, wherever Sodium Iodide NaI:Tl offers too low resolution.

Objective: $LaBr_3$:Ce,La has an intrinsic activity due its Lanthanum ^{138}La content [5], objective of this work is to provide a **Machine Learning** based solution for improving automatic gain stabilization.

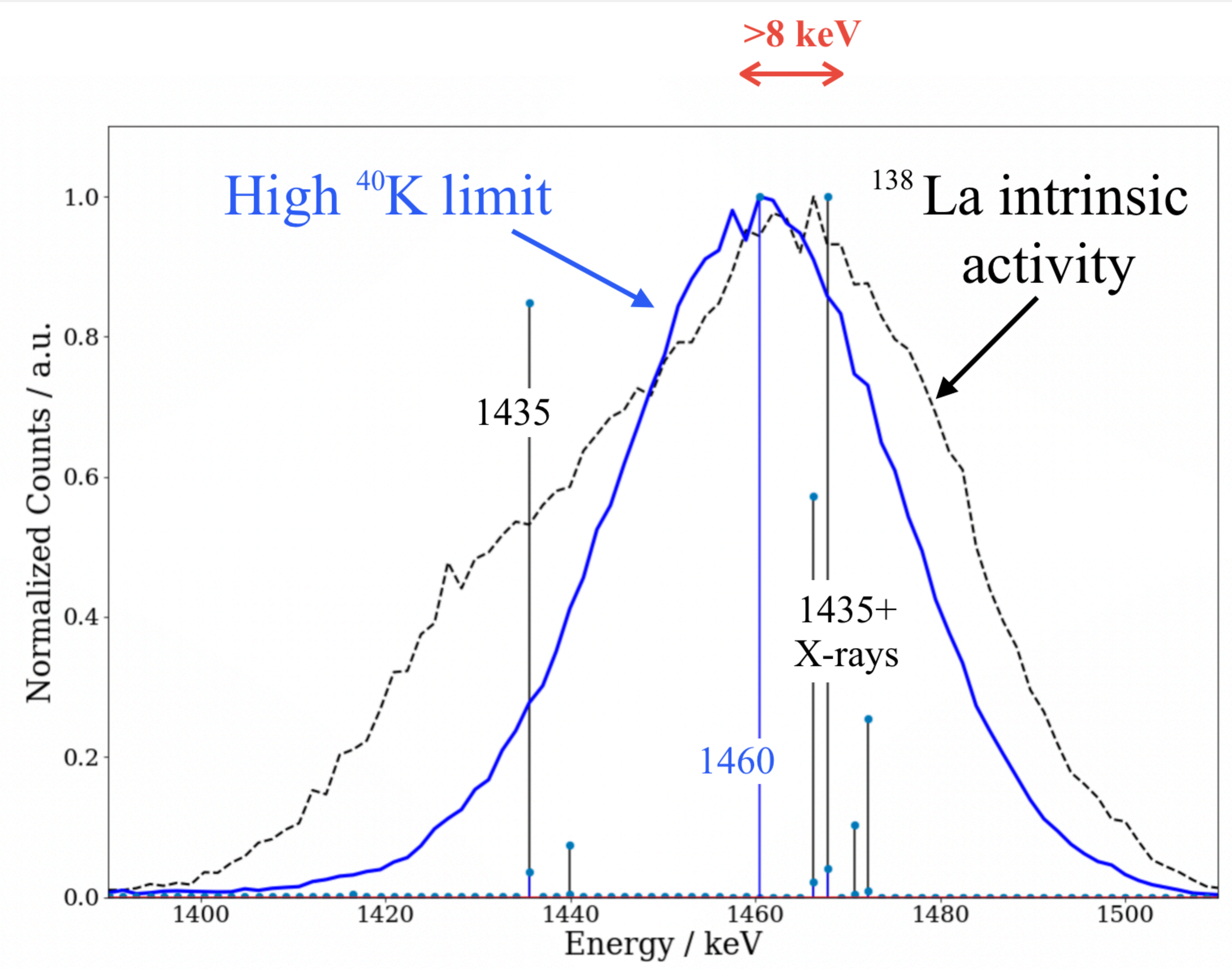

Figure 1: Monte-Carlo-Simulation with tRAYcy showing the intrinsic activity – the pure ^{138}La limit (spectrum = black dashed line, energy positions = black lines)–, versus the high ^{40}K limit (spectrum = blue line, energy position at 1460keV = blue).

1.2 tRAYcy Monte-Carlo code

The **tRAYcy** Monte Carlo (MC) code is a ray-tracing based MC algorithm designed to enhance gamma spectroscopy. It simulates detector response functions and gamma radiation detector spectra. These simulations facilitate advancements in the analysis of gamma radiation spectra, particularly in:

- Mathematical calibration,
- Geometry correction,
- Summing correction,
- Spectrum deconvolution.

In this work, we apply the **deconvolution** technique to analyze the prominent peak structure observed at 1435+ keV in $LaBr_3$ detectors. Using tRAYcy, we examined the composition of the 1435+ keV structure and successfully separated it from the ^{40}K contribution (see Fig. 1).

1.3 Intrinsic activity

Relevant lines of ^{138}La [5], [6]:

Mode	Ratio	Half life	X-rays / keV	γ-Lines / keV
ε	65.5%	$1.03 \times 10^{11}a$	31.81, 32.194, 36.304, 36.378,37.255	1435.8
β^-	34.5%	$1.03 \times 10^{11}a$	34.279, 34.72, 39.17, 39.258, 40.228	788.742

- Measurement is inside the crystal $\rightarrow$ X-rays and γ-Line coincident
- Result: Complex peak structure at 1468 keV - 1472 keV, please refer to Fig. 1
- Structure is often used for automatic stabilization
- Line is close to the γ-Line 1460 keV of Potassium ^{40}K

Depending on ^{40}K presence in natural background, two fundamental limits can be found:

1. The **High-K-limit**, potassium amount κ overwhelms the intrinsic activity λ, $\kappa \gg \lambda$
2. The ^{138}**La-limit**, amount κ of ^{40}K is lower than λ, $lambda \gg kappa$

2 Decision Trees

2.1 Introduction

- Supervised learning paradigm, discussed by Breiman et al. [7]
- Commonly uses the **information gain IG**, based upon the **information entropy** to find the data variable that
- Can be formulated as supervised **classification** or **regression** algorithm

2.2 Gini Impurity

- Probability for choosing ith item = p_i
- Probability for wrong categorization $\sum_{k \neq i} p_k = 1 - p_i$
- Definition of **Gini Impurity** I:

$$G = 1 - \sum_i p_i^2 \quad (1)$$

3 Monte -Carlo -Simulation with tRAYcy

- Simulation of spectral distributions $\psi(E|\kappa, \lambda)$ with **tRAYcy**
  - κ: Weight factor modelling the ^{40}K contribution, cf. Subsection 1.2
  - λ: Weight factor modelling the ^{138}La contribution, cf. Subsection 1.2

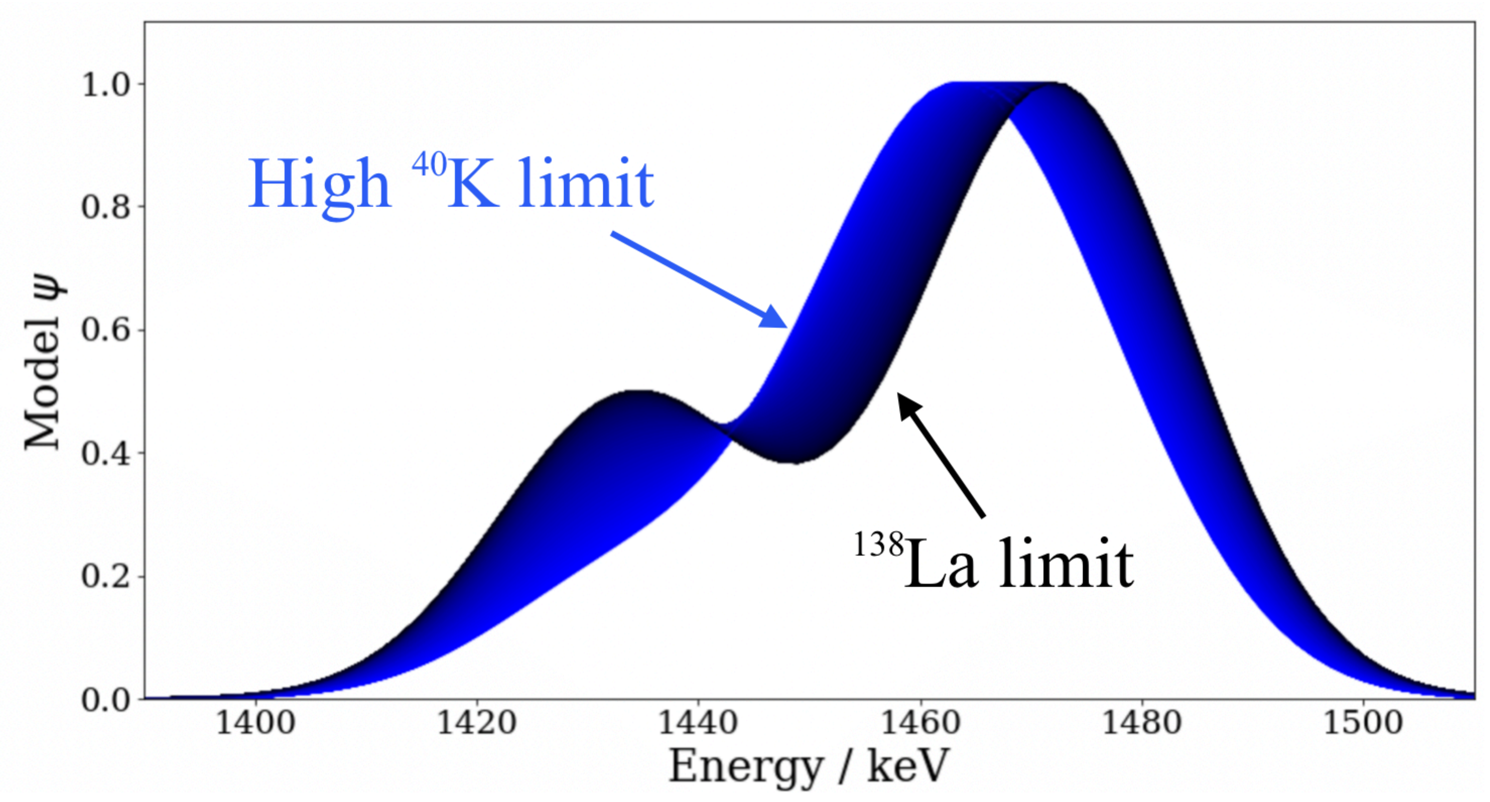

Figure 2: Transition of probability distribution $\psi(E|\kappa, \lambda)$ from $(\lambda = 1, \kappa = 0$ to $\lambda = 0, \kappa = 1)$

Algorithmic procedure:

- Generate 20,000 distributions $X_{\text{Train}} = \psi(E|\kappa, \lambda)$
- Equidistant grid from $\psi(E|\kappa = 1, \lambda = 0)$ to $\psi(E|\kappa = 0, \lambda = 1)$, see Fig. 2
- $c = \kappa/\lambda$ defines precision peak shape and $Y_{\text{Train}} = c$
- Train **Decision Tree** $\mathcal{T}[\psi(E)]$ based on **Gini Impurity** (1) with $(X_{\text{Train}}, Y_{\text{Train}})$
- Use $\mathcal{T}[\psi(E)]$ as predictor of peak position, allowing precise automatic calibration

4 Tests

Handheld radioisotope identification device (RIID) based on $LaBr_3$:Ce,Sr

- Tested in climate chamber, ramping temperatures from -20° to 55° to test gain shift behaviour
- Variation of different amounts of additional ^{40}K that is added to the chamber and continuous evaluation of $c = \mathcal{T}[\psi(E)]$ to estimate fine gain modifier Δf_g
- Stabilization keeps gain calibration within $\pm 0.1 keV$

References

[1] S. W. Squillante, T. Johnson, R. Hawrami, R. Schmall, M. R. Squillante, and P. J. Sellin, "A new scintillator for gamma-ray spectroscopy: Ce3+-doped LaBr3," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 458, no. 1-2, pp. 61–67, 2001.

[2] H. Zhang and et al., "Performance evaluation of a labr3:ce scintillation detector in a brain pet scanner," *Physics in Medicine & Biology*, vol. 64, no. 13, p. 135017, 2019.

[3] A. Wójtowicz and et al., "Application of labr3(ce) scintillation detectors in nuclear safeguards measurements," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 831, pp. 332–339, 2016.

[4] L. T. Hudson, J. T. Trammell, D. L. McDaniel, and T. W. Robertson, "Development and evaluation of labr3-based gamma-ray detectors for homeland security applications," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 604, no. 1-2, pp. 185–187, 2009.

[5] R. Grzywacz, R. Grzywacz, and et al., "Radiation background of labr3(ce) scintillators," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 615, no. 2-3, pp. 587–593, 2010.

[6] L. e. a. Nicoletti, "Measurement of radioactive contamination in labr3(ce) crystal scintillators," *Journal of Instrumentation*, vol. 5, no. 05, p. P05008, 2010.

[7] L. Breiman, J. Friedman, C. J. Stone, and R. A. Olshen, *Classification and Regression Trees*. Chapman & Hall/CRC, 1984.