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A new Prototype Detection System Based on the Beta-Gamma Coincidence Technique for Radioxenon Measurement

S. Azimi[1], H. Afarideh[1], Lucie Fiserova[2]

[1] *Faculty of Energy Engineering and Physics, Amir Kabir University of Technology, Tehran, Iran*

[2] *NUVIA a.s., Prague, Czech Republic*

Amirkabir University of Technology (Tehran Polytechnic)

INTRODUCTION

A new radioxenon detection system based on beta-gamma coincidence has been developed and calibrated, using NaI(Tl) and silicon detectors.

METHODS/DATA

The new prototype system was tested with ^{222}Rn and ^{131m}Xe sources.
A ^{166m}Ho source has been employed for energy calibration and performance check of the silicon detector.

START

RESULTS

The results demonstrated good energy resolution for the discrimination of radioxenon isotopes.

CONCLUSION

The proposed prototype provide a foundation for the development of operational systems with an optimized geometry.

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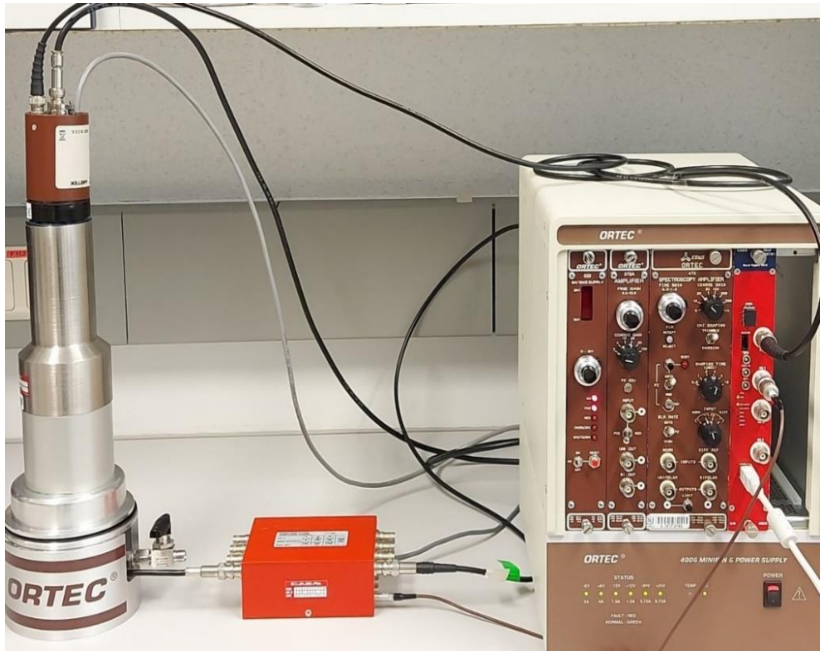
Introduction

In this research, a novel detection system for radioxenon is developed, aiming to enhance the sensitivity of detection in laboratory analysis. The designed system is a new prototype which is tested by injecting the ^{222}Rn and its daughters (^{214}Pb and ^{214}Bi) as a beta–gamma emitter and also ^{131m}Xe gaseous sources, which are of interest to the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO). To calibrate and verify the system, a ^{166m}Ho source is utilized. This detection system comprises a gamma and X-ray radiation detector, specifically NaI(Tl), and a silicon detector for detecting beta particles or conversion electrons. The inclusion of silicon aims to improve energy resolution and reduce the likelihood of memory effect in comparison to a scintillator detector. Coincidence parameters are established using a list-mode multi-parameter data acquisition system, and the efficiency of the two detectors and minimum detectable activity (MDA) are determined.

Material and measurement setup

- PIPS detector with a 500 µm thickness
- Sodium iodide gamma scintillation detector NaI(Tl) with 76 mm×76 mm diameter
- Air-tight aluminum cell with a sample gas volume of 48.8 ml and 1 mm thickness
- Ortec vacuum chamber and vacuum pump with a vacuum gauge ranging from zero to 1000 mTorr
- Preamplifiers for PIPS and Na(Tl) detectors
- N6781 Dual/Quad Digital Multi-Channel Analyzer (MCA)
- High-gain CAEN amplifiers



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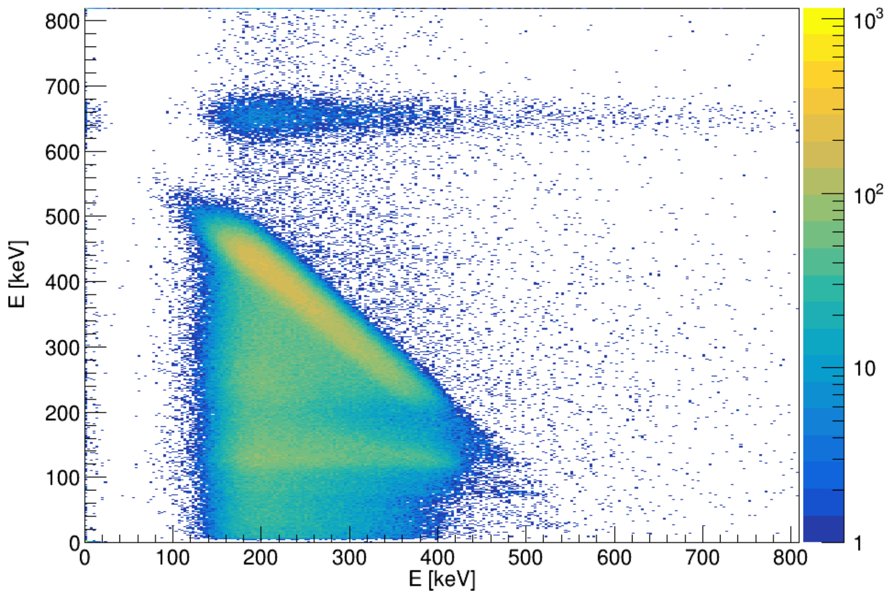
Detector energy calibrations

Calibration of the gamma detector: Using the gamma sources with known energies included ^{241}Am (59.54 keV), ^{57}Co (122.06 keV), ^{137}Cs (661.67 keV, 32.8 keV), ^{133}Ba (31 keV, 81 keV, 302 keV, 356 keV), and ^{22}Na (511 keV).

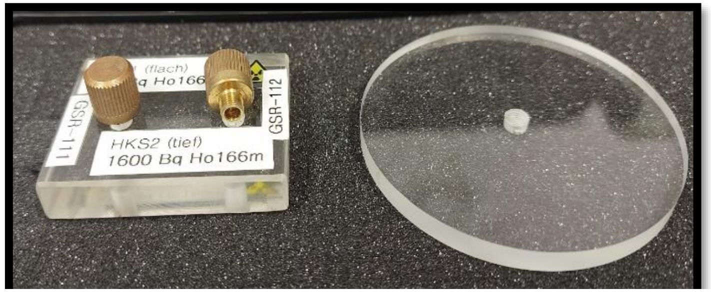
Calibration of the beta detector: Using two sources of ^{137}Cs and ^{166m}Ho with two different methods (Compton scattering and calibration with known electron energies) to validate the system performance.

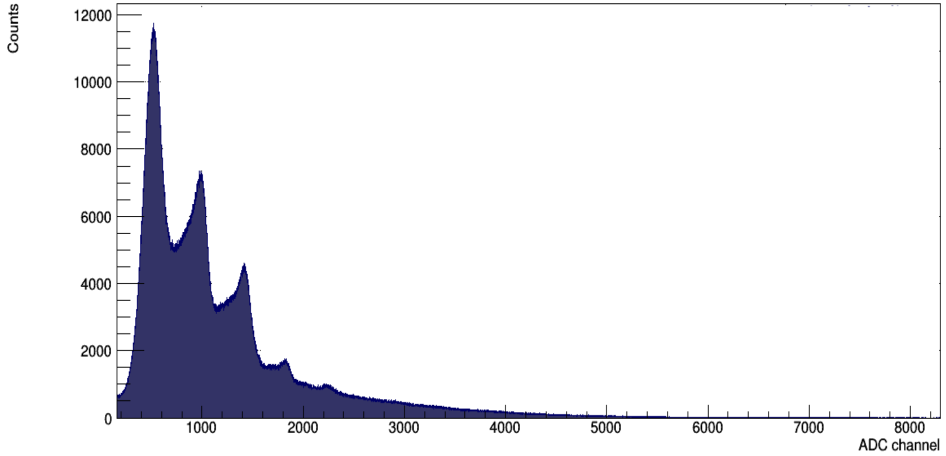


Above: The 2D coincidence calibrated histogram resulting from Compton scattering of ^{137}Cs in the PIPS and the NaI(Tl) crystal

Right up: The ^{166m}Ho beta energy calibration source

Right down Conversion electron spectrum of the ^{166m}Ho source





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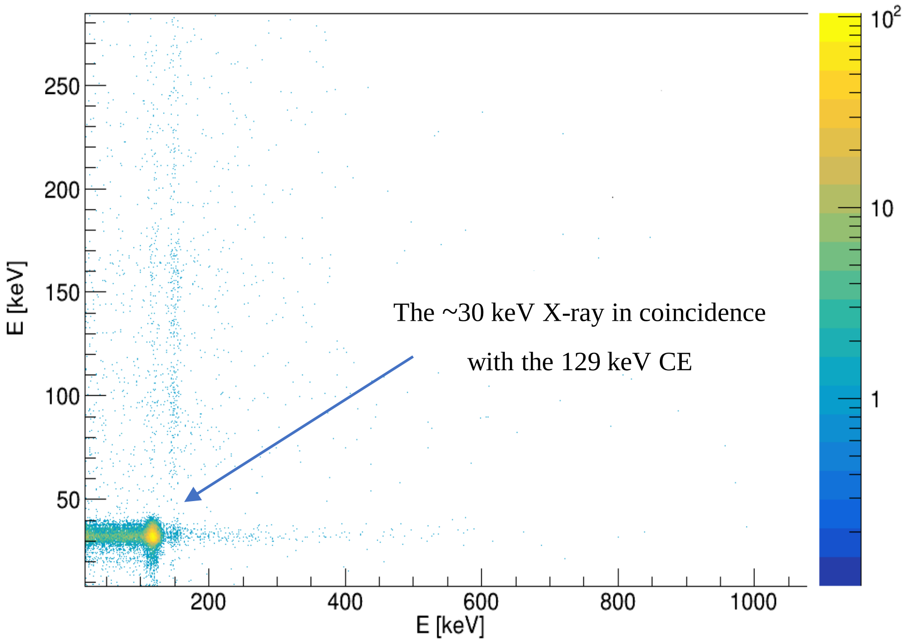
Results

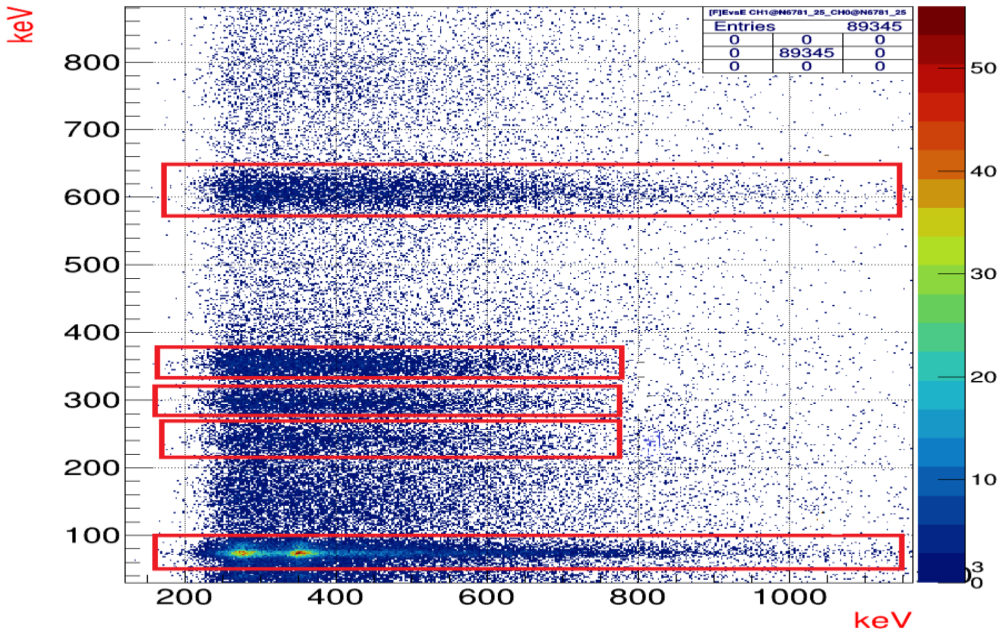
^{131m}Xe measurement

The ~30 keV X-rays in coincidence with 129 keV conversion electrons (CE) caused a significant ROI in the coincidence spectrum of ^{131m}Xe.



Radon measurement

^{214}Pb and ^{214}Bi are produced by the decay of ^{222}Rn with 3.8 days half-life. They are emitters of beta and gamma in coincidence which are relevant to radioxenon isotopes and interesting to detect in our system for a performance test.



There are adequate separations between the energies of interest due to the good detector energy resolution

Quantification results

18-hour measurement

Energy resolution

7.8% for the 129-keV ^{131m}Xe conversion electron
18.11% for the summed ~31 keV X-ray peaks

Detection efficiencies

The coincidence detection efficiency ($\varepsilon_{\beta\gamma}$) about 0.015 ± 0.0012% for ^{131m}Xe (~31 keV + 129 keV)
The absolute efficiency for the NaI(Tl) is 1.18 ± 0.06%
The absolute efficiency for PIPX detector is 0.024 ± 0.001%

Minimum detectable activity

MDA for pure ^{131m}Xe is 625 mBq

The results are discussed in a submitted paper that is currently under review.

Conclusion

The proposed prototype detects and characterizes radioxenon isotope by measuring beta/CE and gamma/X-ray coincidence. We tested the system's primary parameters, including minimum detectable activity (MDA), energy calibration of both channels, energy resolution, and efficiencies quantification.

The results showed that the PIPS detector can significantly improve the resolution of the 129 keV ^{131m}Xe conversion electron peak, from about 30% FWHM for the plastic scintillator to 10%. As a result, due to the high energy resolution of the detector, we can distinguish peaks of 129 keV and 159 keV from ^{131m}Xe in scenarios where a plastic scintillator would not be able to do so. Moreover, by using silicon as a beta detector we eliminated the memory effect.

Optimizing the system, improving geometric to 4π solid angle and reducing environmental and electronic noise must be done in the future work to increase efficiency of the beta detector and improve the MDA.

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