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CTBTO Developing An On-Site Inspection System Using Machine Learning

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INTRODUCTION AND MAIN RESULTS

A fully automated system for analyzing radionuclide γ-spectra for on-site inspections (OSI) under the CTBT has been proposed and implemented. The system combines detailed modeling of gamma-quanta interactions in Geant4, automatic search and calibration of photon peaks, and CatBoost models for classifying nuclides and dating mixtures, ensuring efficiency and high accuracy of analysis.

SnT 2025
8 SEPTEMBER ONLINE DAY
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CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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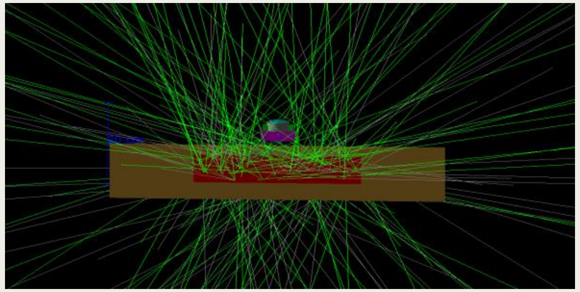
Introduction

Modern methods of nuclear test monitoring also rely on the OSI stage, which requires prompt analysis of aerosol and soil γ-spectra. Traditional methods of manual spectrum analysis are too complicated and time-consuming to process, which limits the efficiency of decision-making. The paper presents a system that includes:

Geant4-modeling of γ-quanta decay and interaction with a detector (taking into account Gaussian "smearing");

Automatic spectrum analysis: photopeak search and calibration (SciPy + LSM);

CatBoost-ML model for classifying radionuclides and regressing the mixture "birth" time.



Visualizing Event Triggering in Simulation

Geant4&ML

A three-dimensional geometry of the Ge detector was built in Geant4. To generate synthetic spectra, gamma decay of radionuclides (I-131, Cs-137, Ba-140, Te-132) was implemented. The interaction of gamma quanta with the detector is modeled through standard Geant4 libraries (photoelectric effect, Compton scattering, ES), which ensures high reliability of physical processes. To bring the calculated peaks in line with the experimental spectra, a Gaussian "smearing" with energy-dependent dispersion (FWHM) was added to each energy.

After loading the spectrum data, the program uses the ML CatBoost algorithm to identify and classify radionuclides by their energy peaks in accordance with the radionuclide database. It outputs a spectrum with identified radionuclides. Then, the birth time of radionuclides is estimated using the activity ratio method and the radioactive decay law

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Peak area Cs-137: 83
Peak area I-131 : 119

Measured ratio A(I-131)/A(Cs-137) = 1.486e+00
Estimation of the time of birth of the mixture: 4.50 day ± 1.66 day
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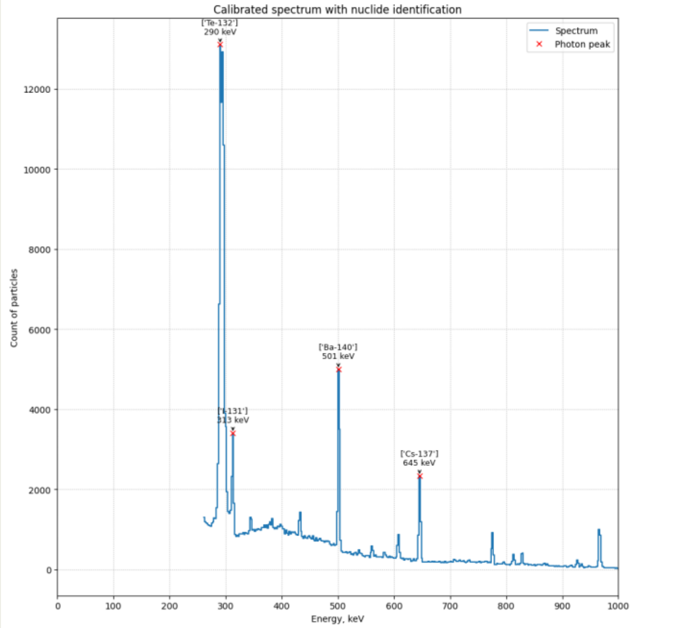
Result of program's work



Spectrum with identified radionuclides

Conclusion

The proposed solution makes a significant contribution to the operational radionuclide monitoring toolkit and strengthening of CTBT verification measures. Its further development and scaling will help to increase the efficiency and reliability of OSI procedures, which is of key importance for global security and nuclear weapons control.

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