Optimizing Gamma-Ray Spectrometry for Charactrization of Low Radioactive Materials

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1. Introduction

Gamma-ray spectrometry is a cornerstone of nuclear analytical techniques, particularly instrumental neutron activation analysis (INAA), where accurate measurement of radionuclide activities is essential for reliable elemental quantification. Despite its wide adoption, uncertainties arising from detector efficiency calibration, energy resolution, and environmental influences continue to challenge analytical accuracy[1,2]. These uncertainties are particularly critical in applications involving trace element analysis, certified reference material (CRM) development, and environmental monitoring, where measurement precision and traceability are important.

High-purity germanium (HPGe) detectors are the primary tools for gamma-ray spectrometry, offering excellent resolution across a broad energy range. However, their performance depends strongly on optimized calibration procedures and long-term stability. Inadequate calibration, poor peak-fitting approaches, or uncontrolled laboratory conditions can result in systematic errors, affecting comparability and confidence in reported results. To overcome these challenges, recent studies have emphasized the need for systematic optimization of spectrometric parameters, including detector efficiency calibration using multi-radionuclide standards, accurate determination of full width at half maximum (FWHM), and effective background subtraction. Additionally, long-term monitoring of detector stability ensures reliable performance, particularly for low-abundance radionuclides where precision is critical [3]. In addition, optimizing the gamma-ray spectrometry is an important factor in k_0 based INAA method for concentration calcuaition[2,4].

In this context, the present work focuses on optimizing gamma-ray spectrometry for the characterization of low-abundance radionuclides, with the aim of improving accuracy and reducing uncertainties at the INAA laboratory, KAERI. As a primary ratio method, INAA is widely applied to the analysis of diverse samples, including the characterization of certified reference materials and the assessment of environmental matrices.

2. Experimental Details

Several mono-photon energy emitting radionuclides (e.g., ^{57}Co) and multi-gamma radionuclides (e.g., ^{133}Ba, ^{152}Eu) were used for calibrating the gamma-ray spectrometry system. The present study focused on energy and efficiency calibration, background evaluation, determination of minimum peak area requirements, and optimization of analog signal processing using the advanced DSPEC-50 spectrometer. Monthly calibration, including background monitoring, was carried out to ensure long-term stability. Special attention was given to the effects of MCA channel selection, FWHM calibration, and background subtraction methods. The INAA laboratory is equipped with several types of detectors: p-type (aluminum end-cap, 0.600 keV at 122 keV), n-type (beryllium end-cap, 0.540 keV at 122 keV), and s-type (carbon end-cap, 0.470 keV at 122 keV), with relative efficiencies ranging from 15% to 55% and an autosampler facility. Low-energy photon detection is limited by the detector type and end-cap material, as shown in Fig. 1. Detector selection depends on the intended application and the target gamma-ray energies.

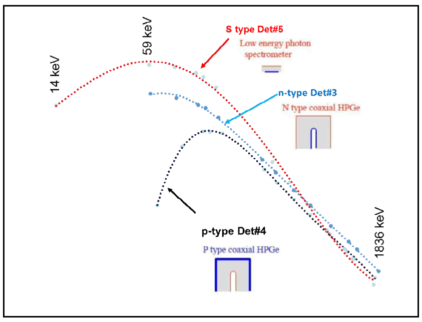

Fig.1 Different detectors efficiencies

3. Results and Discussion

The work included a systematic evaluation of key parameters: (i) minimum net peak area counts, (ii) multi-channel analyzer (MCA) channel selection and its influence on resolution and peak-fitting errors, (iii) calibration protocols for energy, full width at half maximum (FWHM), and detector efficiency using multi-radionuclide standards, and (iv) stability testing under varying environmental conditions. Long-term monitoring of peak positions and background levels demonstrated the importance of periodic calibration and environmental control. Furthermore, optimization of net peak area selection and detector configurations significantly improved detection limits and precision, particularly for low-abundance radionuclides.

Among the evaluated parameters, the minimum net peak area was identified as a critical factor for ensuring accurate results. In this study, a ^{57}Co point source was measured at different counting times to obtain varying net peak areas under fixed geometry. The calculated activities of ^{57}Co, shown in Fig. 2, revealed that lower net peak areas resulted in larger deviations from the certified value, whereas higher peak areas proportionally reduced the deviation and improved accuracy. These results demonstrate that a minimum of 10,000 counts in the target peak is required to achieve realiable and reproducible measurements.

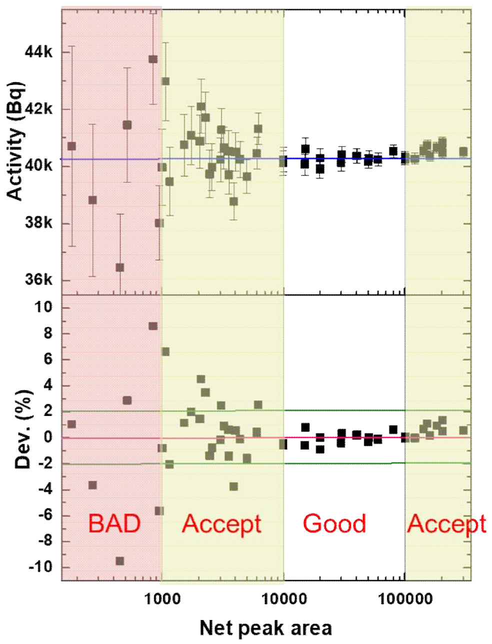

Fig.2 The accuracy of activity determinatuing using netpeak area

The selection of the number of channels per energy is also an important factor in achieving better resolution of the FWHM. A standard point source was measured at a fixed distance of 14 cm from the detector end-cap to minimize coincidence and pile-up effects. For each measurement, the channel settings were varied from 512 channels to 32k channels, as shown in Fig. 3. The results indicated that increasing the number of channels improved FWHM resolution, but the effect became saturated beyond 8k channels. Based on these findings, it was determined that a setting of approximately 8 channels per keV provides reliable results for accurate gamma-ray spectrometry.

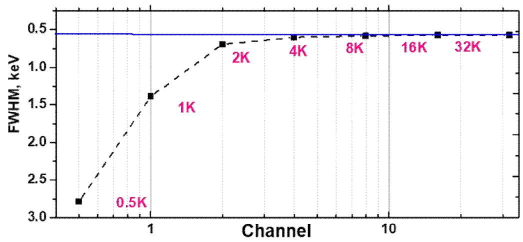

Fig. 3 : Channle vs FWHM

4. Conclusions

This study demonstrates that systematic optimization of gamma-ray spectrometry significantly enhances the accuracy and reliability of low radioactive measurements including INAA. Refinements in detector efficiency calibration using multi-radionuclide standards, evaluation of FWHM, and effective background subtraction contributed to a substantial reduction in uncertainties. Long-term monitoring of gamma-ray spectrometry further confirmed that periodic calibration and stable environmental conditions are essential to minimizing systematic errors. The optimized protocol improved reproducibility across a wide energy range, enabling more precise quantification of trace and minor elements. Overall, the adoption of optimized gamma-ray spectrometry protocols reinforces the role of nuclear analytical techniques in producing high-quality, traceable, and internationally comparable results.

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