Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

A Comparative Study on the Performance of PGNAA Detectors at the KAERI Radiation Equipment Fab.

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***Keywords :** PGNAA, $LaBr_3(Ce)$, GAGG, Thermal neutron, Prompt gamma-ray

1. Introduction

The importance of technology for the real-time, accurate analysis of industrial raw materials like scrap metal is growing for the efficient utilization of circular resources. Prompt Gamma Neutron Activation Analysis (PGNAA) is gaining attention as an effective solution, as it can rapidly and non-destructively analyze the elemental composition of bulk materials.

The Radiation Equipment Fab at the Korea Atomic Energy Research Institute (KAERI) conducts commercialization research to meet the demands of industrial fields, based on its core technologies for radiation detectors, generators, and system integration. As part of the Fab's research activities, this study compared and evaluated the performance of LaBr3(Ce) and GAGG scintillation detectors to secure the core-enabling technology required for developing a PGNAA system for scrap metal analysis.

To this end, samples of major elements found in scrap metal were activated by thermal neutrons, and the emitted prompt gamma rays were measured by each detector. Based on the measured spectra, the gamma-ray spectroscopic performance and elemental analysis capability of each detector were quantitatively evaluated to provide fundamental data for selecting an optimized detector for an industrial PGNAA system.

2. Materials and Methods

In this study, samples of iron (Fe) and potential impurities in scrap metal, such as cobalt (Co) and manganese (Mn), were used. Each sample was activated at the HANARO research reactor at the Korea Atomic Energy Research Institute under a thermal neutron flux of approximately 10^6 n/cm²·sec. To account for detector dead time, the detectors were placed 40 cm from the activated samples, and the gamma-ray spectrum for each sample was measured for 30 minutes. Based on these measurements, an analysis was conducted to determine if each detector could effectively distinguish between iron and the impurities.

The gamma-ray detectors used were 2-inch diameter × 2-inch height $LaBr_3(Ce)$ and GAGG scintillation detectors. A CR-137 photomultiplier tube (PMT) was attached to the rear of each detector to convert the light signals generated by prompt gamma rays into current signals. The output signal from the PMT was then amplified and sorted through a signal processing system, and the final gamma-ray spectrum was acquired using a Peak Sensing ADC (N6741, CAEN). The energy resolution of the implemented detector system, measured at 662 keV (^{137}Cs), was evaluated to be 3.12% FWHM for $LaBr_3(Ce)$ and 8.11% FWHM for GAGG.

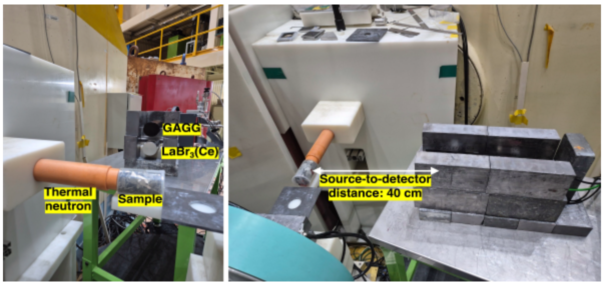

Fig 1. Experimental setup for the performance evaluation of scintillation detectors.

For spectrum analysis, gamma-ray peaks were automatically identified using the Becquerel library[1], and these results were compared with neutron activation data from the literature[2] to analyze the prompt gamma-ray emission characteristics and detector response for each sample.

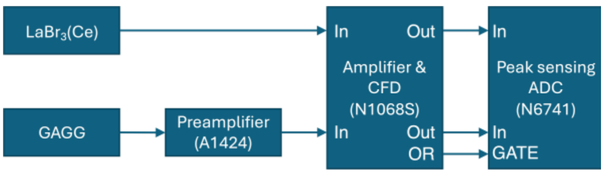

Fig 2. Diagram of the Detector Signal Processing System.

3. Results and Discussion

The thermal neutron capture (n, γ) reaction generally exhibits a high reaction cross-section for emitting prompt gamma rays below 1 MeV. Accordingly, this study compared the gamma-ray spectra within the energy range of 80 keV to 1.1 MeV. Figure 3 displays the primary results, showing the prompt gamma-ray spectra for the impurities (Co, Mn) as distinguished from Fe. In each graph, the top section presents the raw data, the middle section shows the reconstructed spectrum after reducing low-energy noise with the Becquerel library, and the bottom section displays the results of the automatic gamma-ray peak identification.

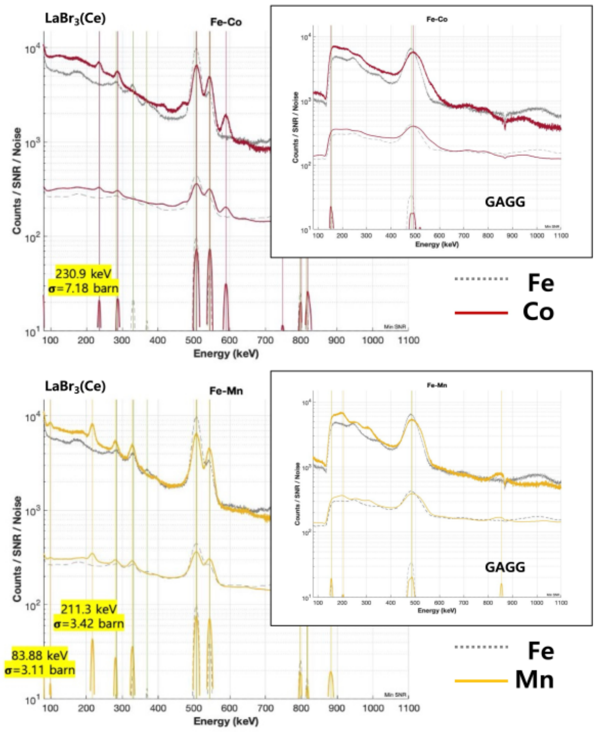

Fig 3. Comparison of prompt gamma-ray spectra from Co (top) and Mn (bottom) samples, measured using $LaBr_3(Ce)$ and GAGG detectors.

For the $LaBr_3(Ce)$ detector, the automatic peak identification results confirmed that the representative peak for the Co sample (red solid line) at 230.9 keV (σ=7.18 barn), as cited in the literature, was clearly distinguishable from Fe (gray dotted line). Similarly, for the Mn sample (yellow solid line), the representative peaks from the literature at 211.3 keV (σ=3.42 barn) and 83.88 keV (σ=3.11 barn) were also clearly distinguishable from Fe.

In contrast, the GAGG detector showed a tendency for multiple energy peaks to linearly combine into a single broad peak due to its relatively low energy resolution. This ambiguity in the positions of individual gamma-ray peaks limited its ability to differentiate elemental characteristics. For instance, while the $LaBr_3(Ce)$ detector clearly identified individual peaks for the Co sample, the GAGG detector exhibited overlapping peaks in the 200 keV to 400 keV range. This characteristic was also observed with the Mn sample, where the overlap of gamma signals was even more pronounced in regions with a high density of peaks.

3. Conclusions

This study performed a preliminary evaluation of $LaBr_3(Ce)$ and GAGG scintillation detectors to determine their suitability for an industrial Prompt Gamma Neutron Activation Analysis (PGNAA) system designed for elemental analysis of scrap metal. The results provide clear guidance on detector selection for field applications where cost-effectiveness and operational efficiency are critical considerations.

The analysis conclusively demonstrated that the $LaBr_3(Ce)$ detector possesses the necessary spectroscopic performance for this application. With a superior energy resolution of 3.12% FWHM at 662 keV, it was able to clearly resolve the characteristic prompt gamma-ray peaks of cobalt (230.9 keV) and manganese (211.3 keV and 83.88 keV) from the complex iron spectrum. This performance confirms that the $LaBr_3(Ce)$ detector is a strong candidate for industrial PGNAA systems, showing potential to serve as a viable alternative to more expensive and cryogenically cooled HPGe detectors. In stark contrast, the GAGG detector, with its relatively poor energy resolution of 8.11% FWHM at 662 keV, proved inadequate for this task. Its tendency to produce broad, overlapping spectral peaks obscured individual gamma-ray signatures, revealing significant limitations for elemental analysis based on thermal neutron capture reactions.

Based on these results, future work will focus on developing a prototype system using the $LaBr_3(Ce)$ detector and conducting validation experiments with actual scrap metal samples. We will also work to improve the gamma-ray peak detection algorithm to enhance the accuracy of quantitative analysis. This research contributes to the overarching goal of the KAERI Radiation Equipment Fab: to develop practical, integrated radiation-based systems for industrial applications.

Acknowledgements

This work was supported by the institutional R&D program of the Korea Atomic Energy Research Institute (Project No. 2710007334), with financial resources from the Ministry of Science and ICT in 2025. This research was also supported by the Technology Development Program of the Ministry of SMEs and Startups [RS-2024-00469068].

REFERENCES

[1] J.H. Kim, K.M. Oh, J.H. Park, et al., Development of a prototype hand-held-type gamma imaging device for Korea Customs Service, J. Korean Phys. Soc., (online first), 2025. https://doi.org/10.1007/s40042-025-01460-0

[2] M. Molná r (Ed.), Handbook of Prompt Gamma Activation Analysis with Neutron Beams, Kluwer Academic Publishers, 2004.