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RE-CHARACTERIZATION OF TWO N-TYPE PLANAR HPGe DETECTORS BASED ON EXPERIMENTS AND MONTE CARLO MODELING

Accurate gamma-ray spectrometry using High Purity Germanium (HPGe) detectors relies on precise knowledge of detector efficiency, particularly the full energy peak efficiency (FEPE), which can degrade over extended periods of operation due to the growth of the detector's inactive dead layer (DL). Despite this known issue, DL correction is rarely performed in long operating detectors, and manufacturer specifications are often taken as fixed. This study emphasizes the gap by presenting a combined experimental and Monte Carlo modeling approach to re-characterize two planar n-type HPGe detector systems – Sys1 and Sys2 – that have been in continuous operation for nearly three decades. Although the detectors share virtually identical geometrical designs, they exhibit differences in performance, attributed primarily to variations in DL thickness. Gamma-ray measurements using certified point reference sources (59.5–1332.5 keV) were conducted, and corresponding Monte Carlo N-Particle (MCNP5) simulations were performed to evaluate the effect of DL variation on FEPE and on the active detector volume. Additionally, MCNP was used to apply source activity corrections, taking into account geometric and attenuation effects. The results offer a validated framework for modeling and correcting FEPE losses in aging detectors. By optimizing the DL thickness for Sys1 and Sys2 to 2.77 and 2.82 mm, respectively, the deviation between the simulated and experimental FEPE was reduced to below 5 %. Beyond nuclear instrumentation, this work has implications for any application requiring high-accuracy spectrometry over long operational timelines, including nuclear safeguards, radioactive waste assay, environmental monitoring, radiation metrology, and nuclear forensics.

Keywords: HPGe detector, full energy peak efficiency, dead layer, MCNP, certified reference point sources.

1. Introduction

High Purity Germanium (HPGe) detectors are regarded as the standard of reference in gamma-ray spectrometry due to their superior energy resolution and stable detection performance. They are indispensable in a wide range of applications, including radiation monitoring, nuclear safeguards, and radioactivity measurements in various types of samples [1]. The full energy peak efficiency (FEPE) of HPGe detectors and other detectors must be determined to ensure reliable activity quantification across various applications, regardless of the intended use [2–5]. Although FEPE experimental determination using standard certified sources is the most accurate method, it is costly, time-consuming, and labor-intensive because each sample setup and geometry must be calibrated with a verified source [6, 7].

Accordingly, Monte Carlo simulations, particularly with codes such as MCNP and Geant4, have become increasingly widespread for modeling detector behavior and calculating efficiency in a wide range of configurations [8–11]. A general-purpose code, such as MCNP, is frequently used for modeling HPGe detectors based on FEPE determination [12]. However, the accuracy of the MCNP simulation depends heavily on the precision of input data parameters, such as the geometric and physical characteristics of the detector. These characteristics include the crystal height and diameter, the internal contact length and diameter, the detector housing measurements, the distance between the crystal and the aluminum entrance window, and the DL thickness. The thickness of the DL – an inactive part of the crystal that forms over time as lithium atoms diffuse into the Ge crystal – plays a key role, particularly for low-energy photons. Throughout the detector's operational life, especially under ambient storage or usage conditions, the DL thickness tends to grow progressively, reducing the detector's active volume and thereby degrading detection efficiency. To determine the detector characteristics, a special procedure called detector characterization is used [13, 14]. Once a detector has been precisely described, the efficiency values for samples in any configuration and composition can be rapidly and reasonably determined without the need for reference materials. To achieve a precise characterization, it is essential to closely monitor the geometric factors provided by the manufacturer, identify any missing characteristics, and regularly assess time-varying metrics, such as DL. Despite its importance, the DL is rarely monitored frequently over a long-term operational period and is often underreported or missing in manufacturer specifications.

Several studies have focused on estimating the DL thickness of HPGe detectors. In one investigation, the detector DL was initially 0.35 mm when first employed in 1996. After 9 yrs of operation, the thickness increased to 1.15 mm in 2005, and after an additional 4 yrs, it reached 1.46 mm in 2009. A separate study reported similar long-term increases in DL thickness, confirming that this parameter changes significantly with extended detector use. [2, 15]. The DL thickness of the p-type detector increased by 0.10 mm over a period of 3 yrs, whereas the n-type detector exhibited an increase of 0.42 mm within 1.5 yrs. [16]. As a result, the DL thickness does not follow a predictable linear trend but varies irregularly with factors such as lithium diffusion dynamics, temperature, and crystal quality. The DL in a typical lithium-n contact is around 700 μm of the inert germanium layer [17]. At room temperature, the drift of lithium is very high in the germanium active volume. As a result, the lithium could spread through the crystal if the detection system is kept at ambient temperature without being cooled for a time, thickening the DL [9, 18]. A study emphasized that prolonged storage of the detectors at ambient temperature led to a gradual increase in their DL thickness [19]. The gradual degradation of the vacuum is another factor contributing to the variation in the DL thickness. According to the study, over time, the active volume decreases, which becomes the primary cause of the gradual variation in DL thickness, influenced by several factors as stated by [20]. The study also observed that noticeable FEPE loss necessitates re-evacuating the detector to correct the vacuum. A proposed method was implemented to determine the surface and lateral DL values. The results showed that the DL thicknesses had increased beyond the manufacturer-specified values, which reduced the deviation between the experimental and simulated results to less than 4 % [21]. Monte Carlo simulations-based studies have shown that DL thickness can grow by about 1.30 mm over 9 yrs, leading to a reduction in HPGe detector efficiency [22]. Using Monte Carlo simulations, a study examines the rise in DL thickness of an HPGe n-type detector between 2012 and 2018. It reveals that the outside lateral thickness increased from 0.08 to 2.27 mm, as indicated by the results [23]. The main gap is that few studies have addressed DL time-dependent evolution across decades of detector use or validated the changes with both experimental and simulation data. A gap remains in applied methods for analytically re-characterizing aging detectors to correct for DL-related efficiency degradation, particularly without relying on extensive recalibration with reference sources. In this study, two detection systems are examined, referred to as Sys1 and Sys2. Sys1 is an n-type planar HPGe detector previously characterized in [24], where its DL had increased to nearly six times its 2005 value [25, 26]. Sys2, from the same model family, is a similar detector operated under different conditions, including a different applied voltage. Although structurally comparable, the two systems differ in operational history and DL evolution, enabling a direct performance comparison.

This study introduces a validated methodology for re-characterizing HPGe detection systems following extended operational periods of nearly three decades. The work focuses on two n-type HPGe detectors with virtually identical geometric configurations but different service lifetimes, enabling a targeted investigation into the impact of long-term use, particularly changes in DL thickness. Experimental measurements were performed using certified reference point sources that emit gamma rays from 59.5 to 1332.5 keV, allowing for comprehensive efficiency profiling across a broad energy range. To support and interpret these measurements, detailed MCNP simulations were conducted to model the effect of varying DL thickness on detector efficiency and active volume. Additionally, MCNP was applied to perform source activity corrections, accounting for geometrical and attenuation factors that affect quantitative accuracy in practical calibration setups. This integrated approach – combining long-term detector comparison, experimental benchmarking, and MCNP-based modeling – provides a robust framework for understanding performance drift and improving calibration precision in aging spectrometric detection systems. The findings provide a validated method for assessing and correcting efficiency loss in aging HPGe detection systems. This not only confirms the effectiveness of the proposed approach but also highlights a cost-efficient strategy for extending the functional life of HPGe detectors, avoiding unnecessary replacement, and improving performance in critical radiation measurement applications.

2. Materials and methods

2.1. Experimental setup

The Canberra multichannel analyzers and two n-type planar HPGe detectors (model GL0515R, Canberra fabrication) were part of the experimental setup, featuring resolutions of 540 and 520 eV at 122 keV (^{57}Co), respectively. The Low Energy Germanium detectors used in this study were characterized based on the manufacturer’s nominal specifications, including crystal dimensions, active volume, and energy resolution. The detection systems with a core hole that is 1.159 mm in radius and 0.50 mm in height have been reported to have a diameter of

25.50 mm and a height of 15.50 mm for the germanium crystal. Additionally, it features an aluminum end cap, which is 78 mm in diameter and 1 mm thick, and a 0.4 µm thick boron layer. The end cap is placed 5 mm from the upper surface of the instrument crystal. Additionally, the detectors have initially measured surface DLs of 0.389 and 0.396 mm in thickness, respectively. Since the operation in 1996, the employed detector nominal efficiency has been less than 15 %. The detector is coupled to a 5-liter liquid nitrogen cooling system and a model 7905SL-5 cryostat.

To record events based on pulse height as a single metric, the detection system used in this experiment was integrated with a standard module, the Inspector Multi-Channel Pulse Height Analyzer (model IN2K). The detectors were configured on a multichannel analyzer with 8k channels, providing a calibrated energy range of approximately 10 to 3000 keV, and a high voltage of –2500 and –2000 V. The Genie 2000 software, included with the Canberra system, is used to acquire the gamma spectra. The experimental efficiency and its associated uncertainty were determined as described in Eqs. (1) and (2) using certified reference point sources. The sources included ^{133}Ba (37.8 kBq, γ energies: 81, 276, 303, and 356 keV), ^{137}Cs (38.6 kBq, γ energy: 662 keV), ^{60}Co (40.2 kBq, γ energies: 1173 and 1332 keV), and ^{241}Am (34.2 kBq, γ energy: 59.5 keV). Each point source had an active diameter of 5 mm and was encapsulated in a holder surrounded by an aluminum ring with a diameter of 30 mm and a thickness of 4 mm.

$$\varepsilon_{Exp}(E)=N(E)/\left(A\cdot Y_{\gamma}(E)\cdot T\right), \qquad (1)$$

$$\sigma\varepsilon_{Exp}(E)=$$

$$=\varepsilon_{Exp}(E)\sqrt{\left(\sigma A/A\right)^{2}+\left(\sigma N(E)/N(E)\right)^{2}+\left(\sigma Y_{\gamma}(E)/Y_{\gamma}(E)\right)^{2}}, \qquad (2)$$

where $N(E)$ are counts in the full energy peak at a particular energy (E), T is live time, A is the activity of the source at the time of counting, $Y_{\gamma}(E)$ is the percentage gamma-ray emission probability, $\sigma\varepsilon_{Exp}(E)$ is the statistical uncertainty in efficiency, $\sigma N(E)$ is the statistical uncertainty of counts in the full energy peak, $\sigma Y_{\gamma}(E)$ is the statistical uncertainty in the gamma emission probability, and σA is the statistical uncertainty associated with the activity of the standard source.

The counts in the total energy peak were corrected by subtracting the background radiation counts in order to provide precise measurements. Furthermore, to obtain a sufficient count rate with acceptable counting statistics, the experiment was conducted in three runs per sample, with a total measuring time ranging from 300 to 17000 s/run. For instance, sufficient counting statistics are considered to exist when there are at least 10000 counts.

Furthermore, the tests were carried out under optimal conditions by modifying the distance between the sample and the detector entrance window at a distance of 10 cm, where the dead time was reduced to less than 1 %, i.e., in order to ensure high-quality spectra of good shapes of full energy peaks and minimize peak count losses.

2.2. Monte Carlo modelling

To build a model for a germanium detector, MCNP was applied for the simulation of the transit of radiation [27]. A simulation model based on the manufacturer's nominal detector parameters is shown in Fig. 1 for both the germanium detector and the certified reference point source being tested. The gamma-ray emissions from the source were simulated as isotropic and homogeneous. The simulation approach took into account a few crucial variables and assumptions. The manufacturer states that the detector crystal is made of germanium, which has a cylindrical shape, and the core hole in the middle of the detector also has a cylindrical geometry. In addition, the model incorporated the surrounding aluminum holder. It was expected that the DL would consist of germanium material with a density comparable to that of the crystal, even though lithium diffusion into the crystal occurred in both detectors. Moreover, the simulation took into account all elements of the immediate surroundings, including the air and vacuum.

Using the previously mentioned MCNP model, the FEPE of the detectors was simulated, representing their response function [28]. The simulation procedure involved the pulse height tally (F8 in MCNP) to simulate the detector response, defined as the deposited energy in the detector crystal by radiation emitted from the certified reference point sources at various measurement positions [29]. This simulation, consisting of 36 input files (for geometry setup simulation scenarios), has an average runtime of 43 min. The number of source particles was chosen to be sufficiently large, with 10^{7} histories, to ensure appropriate statistics for certified reference point sources and to obtain a statistical error for the computed FEPE of less than 3 %.

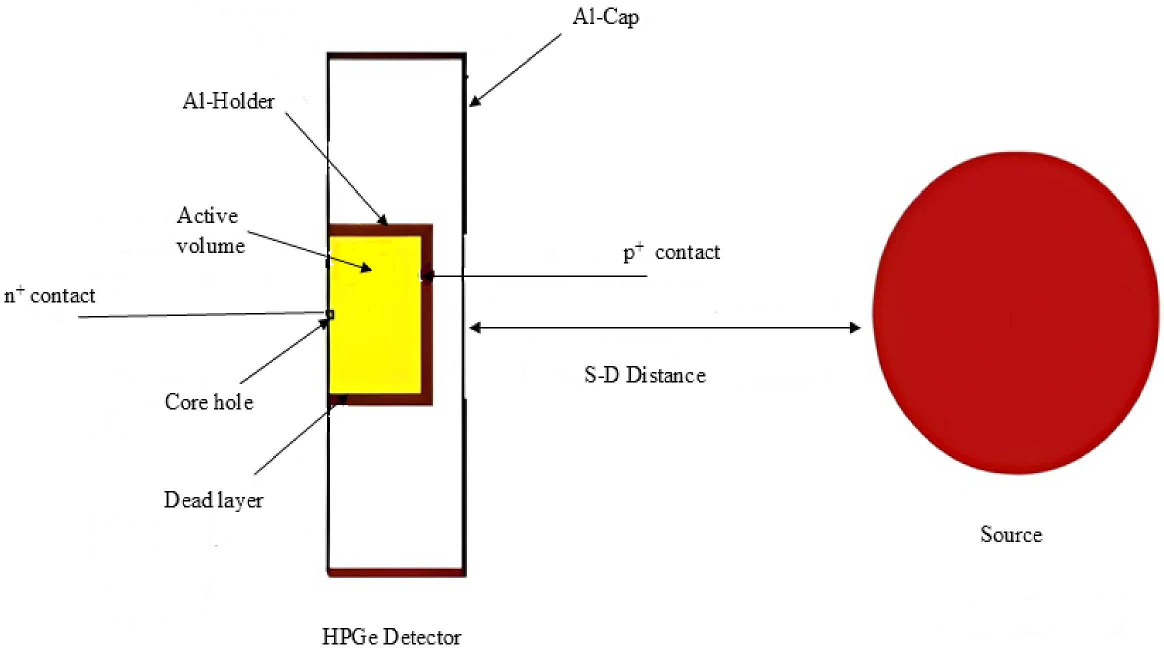

Fig. 1. Schematic diagram of the detector-to-source geometry setup.
(See color Figure on the journal website.)

3. Results and discussion

3.1. Estimation of the DL thickness of Sys1

Various photon energies were used in the experiments, and certified reference point sources were placed 10 cm away from the detector entrance window to acquire experimental efficiency. With a nominal DL thickness of 0.389 mm, the simulated and experimental values differed by up to 24 %. Table 1 provides the FEPE results from the experiment and MCNP algorithms at the nominal and optimized DL thicknesses. The DL thickness was determined using a trial-and-error method, with thickness being gradually optimized in predetermined steps until the simulated FEPE matched the experimental efficiency within an acceptable deviation of less than 5 %. The corresponding thickness at this point was defined as the optimized DL value, which was subsequently compared with the nominal value provided by the manufacturer. Seven DL values were considered by multiplying the nominal thickness provided by the manufacturer by scaling factors of 1.1, 2.1, 3.1, 4.1, 5.1, 6.1, and 7.1 to the nominal DL value provided by the manufacturer. They were gradually varied in the detector model step by step until the discrepancy from the experimental efficiency was below 5 %. Increasing the assumed values to more than 7.1, the deviation from experimental efficiency is observed to be greater than 5 %. Thus, multiplying the nominal value by 7.1 yielded the optimized DL in the model, corresponding to a value of 2.77 mm. Subsequently, the FEPE results for Sys1 were found to be close to the experimental values. After 28 yrs of use, it was discovered that the DL of Sys1 had thickened to 2.77 mm. This thicker DL decreases the detector active volume and, consequently, its efficiency.

Table 1. **Experimental and simulated FEPE for Sys1**

Nuclide	Energy, keV	Experimental FEPE ($\times10^{-3}$)	Simulated FEPE ($\times10^{-3}$) at nominal DL	Deviation from experiment, %	Simulated FEPE ($\times10^{-3}$) at optimized DL	Deviation from experiment, %
^{241}Am	59.5	3.1080 ± 0.6000	3.8632 ± 0.0010	+24.2985	3.1938 ± 0.0010	+2.7606
^{133}Ba	81.0	3.6460 ± 0.6000	4.2221 ± 0.0010	+15.8008	3.7988 ± 0.0010	+4.1908
^{133}Ba	276.4	0.6930 ± 0.6000	0.8060 ± 0.0030	+16.3059	0.7252 ± 0.0010	+4.6465
^{133}Ba	302.9	0.5180 ± 0.6000	0.6071 ± 0.0010	+17.2007	0.5437 ± 0.0010	+4.9614
^{133}Ba	356.0	0.4240 ± 0.6000	0.5065 ± 0.0010	+19.4575	0.4097 ± 0.0010	–3.3726
^{133}Ba	383.9	0.3790 ± 0.6000	0.4588 ± 0.0010	+21.0554	0.3613 ± 0.0010	–4.6702
^{137}Cs	661.7	0.1928 ± 0.0500	0.2347 ± 0.0020	+21.7323	0.1865 ± 0.0020	–3.2676
^{60}Co	1173.2	0.0769 ± 0.0200	0.0938 ± 0.0020	+21.9766	0.0743 ± 0.0020	–3.3810
^{60}Co	1332.5	0.0641 ± 0.0200	0.0779 ± 0.0020	+21.5289	0.0624 ± 0.0020	–2.6521

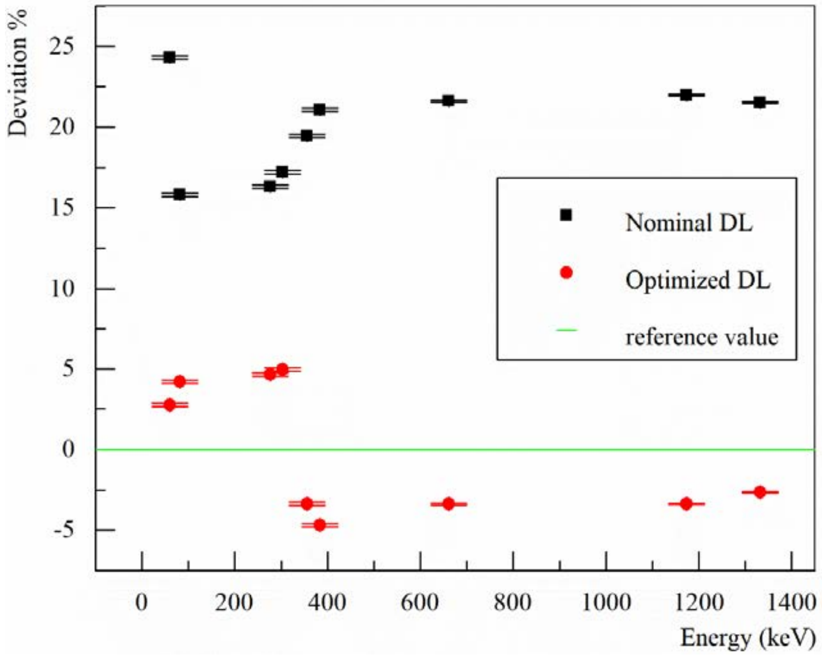

Fig. 2. Relationship between the deviation of the simulated FEPE from the experimental FEPE for Sys1, using the nominal DL of 0.389 mm, and the optimized DL of 2.77 mm. (See color Figure on the journal website.)

Figure 2 shows that when the DL thickness is set to 2.77 mm, the MCNP calculations yield a maximum deviation from an experiment efficiency value of less than 5 %. Moreover, the deviation of the FEPE was observed in both low and high-energy regions when using the nominal and optimized values. It was noted that the deviation is higher in the case of lower energies than in the case of higher energies because the photon attenuation is higher in the case of lower energies. Using the optimized DL value, the deviation points exhibit minimal variation and remain close to the reference line (solid line), with the lowest deviation recorded at 2.65 %.

3.2. Estimation of the DL thickness of Sys2

Table 2 shows that the FEPE results obtained from MCNP modeling using the optimized DL thicknesses are in much better agreement with the experimental values. The deviation is reduced to approximately 3 % when using the optimized parameters, compared to about 52 % when using the nominal DL specified by the manufacturer at the time of fabrication. Moreover, the results of the DL thickness of Sys2 are higher than those of Sys1, meaning that the FEPE results for Sys2 are more deviated from the experiment values. The MCNP simulation has been successfully re-characterized for both detection systems based on the estimated DL values. These simulation results matched the experiment and demonstrating MCNP's capability to define all detector parameters in the input file.

Table 2. **Experimental and simulated FEPE for Sys2**

Nuclide	Energy, keV	Experimental FEPE ($\times10^{-3}$)	Simulated FEPE ($\times10^{-3}$) at nominal DL	Deviation from experiment, %	Simulated FEPE ($\times10^{-3}$) at optimized DL	Deviation from experiment, %
^{241}Am	59.5	2.8150 ± 0.6000	4.2794 ± 0.0010	+52.0213	2.8865 ± 0.0010	+2.5399
^{133}Ba	81.0	3.3120 ± 0.6000	4.8388 ± 0.0010	+46.0990	3.4170 ± 0.0010	+3.1703
^{133}Ba	276.4	0.4130 ± 0.6000	0.6034 ± 0.0010	+46.1016	0.4261 ± 0.0010	+3.1719
^{133}Ba	302.9	0.2312 ± 0.6000	0.2895 ± 0.0010	+25.2163	0.2381 ± 0.0010	+2.9844
^{133}Ba	356.0	0.1200 ± 0.6000	0.1368 ± 0.0010	+14.0000	0.1228 ± 0.0010	+2.3333
^{133}Ba	383.9	0.0824 ± 0.6000	0.0947 ± 0.0010	+14.9272	0.0838 ± 0.0010	+1.6990
^{137}Cs	661.7	0.0421 ± 0.0500	0.0362 ± 0.0020	–14.0143	0.0419 ± 0.0020	–0.4751
^{60}Co	1173.2	0.0214 ± 0.0200	0.0184 ± 0.0020	–14.0186	0.0213 ± 0.0020	–0.4673
^{60}Co	1332.5	0.0151 ± 0.0200	0.0131 ± 0.0020	–13.2450	0.0152 ± 0.0020	+0.6623

Figure 3 shows that the influence of DL thickening is most noticeable in the lowest energy region, at a nominal DL thickness of 0.396 mm. At low energies, it deviates significantly from the experimental value by up to 52 %, but at higher energies, it is roughly 14 % lower. Based on the modeling results,

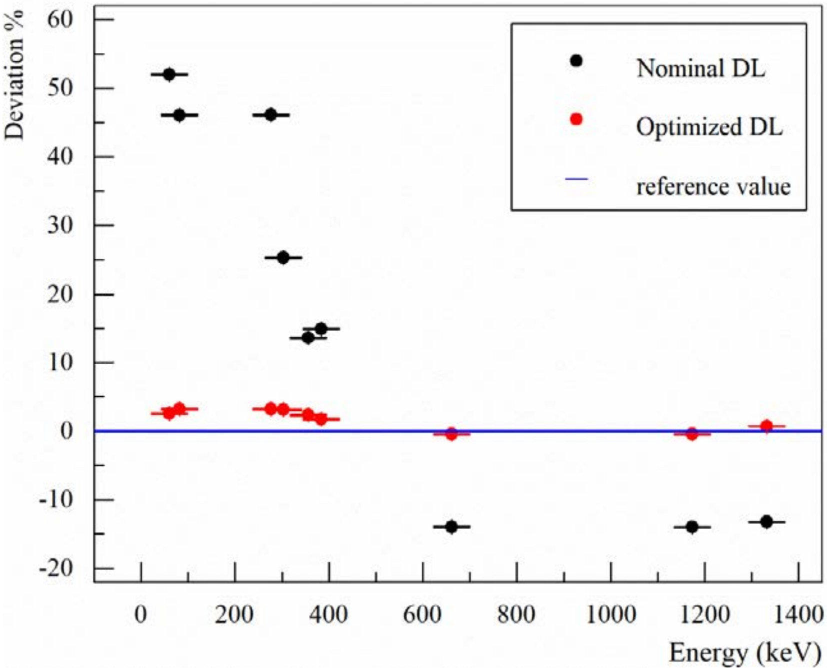

Fig. 3. Relationship between the deviation of the simulated FEPE from the experimental FEPE for Sys2, using the nominal DL of 0.396 mm, and the optimized DL of 2.82 mm. (See color Figure on the journal website.)

it was found that the DL of the Sys2 detector thickened to 2.82 mm over 28 yrs of operation. In addition, there was a tendency for the deviation to have lower values as it get closer to the reference line (solid line) because the differences between the MCNP simulation results and the experimental measurements in the range of energy of 59.5 to 1332.5 keV were up to 3 % at the optimized DL thickness compared to the 52 % maximum difference using the nominal DL value. It can be summarized that the initial DL thickness is subject to progressive variations due to various factors, including detector aging, prolonged radiation exposure, temperature variations, impurities introduced during fabrication, and mechanical or environmental stresses.

3.3. Evaluation of the response function for the used detection systems

Figure 4 illustrates the FEPE results for detection systems at the nominal and optimized DL values.

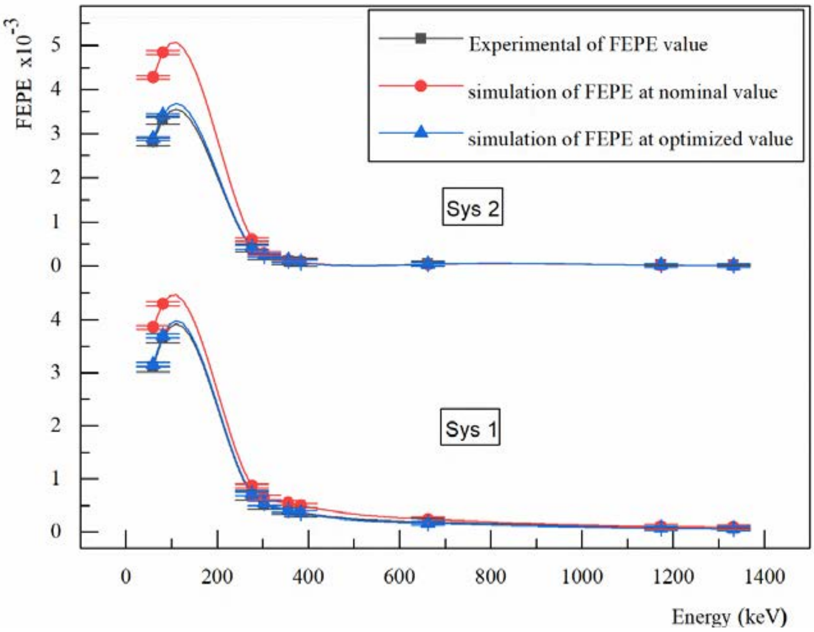

Fig. 4. Comparison of experimental and simulated FEPE for Sys1 and Sys2 at various energies using both nominal DL values of 0.389 and 0.396 mm; and optimized DL values of 2.77 and 2.82 mm, respectively. (See color Figure on the journal website.)

At the nominal DL thickness, the simulated FEPE curves diverge noticeably from the experimental measurements for both systems. This divergence likely arises because not all interacting photons were fully registered by the detector, suggesting a reduction in the effective active area of the detector. The actual DL value was estimated using a trial-and-error approach. In this method, the DL thickness was gradually increased until the deviation between the simulated and experimental FEPE values was minimized. Once the optimized DL was identified, the deviation was reduced to less than 5 %. Therefore, the optimized DL obtained from the MCNP model can be used as the current real value. Vacuum diminishing with time and the detector's inappropriate surroundings are the two main causes of the DL growth. The primary reason Sys2 exhibits higher deviation values than Sys1 is that it has been used less frequently and left without cooling, which prevents it from being maintained under optimal operating conditions for an extended period. The optimized DL values for the detectors were determined using MCNP modeling, and a subsequent characterization of the detectors was performed. The deviation between the experimental FEPE and the simulated values for the nominal and optimized DL is highest at 59 keV and decreases with increasing energy. It reaches an average value in the intermediate energy range of 120–670 keV and continues to decrease, becoming approximately constant at higher energies up to 1332 keV, as shown by the curves for both detection systems in Fig. 4. The observed behavior is attributed to the high attenuation of gamma rays at low energies compared with the lower attenuation at higher energies. Consequently, variations in the DL thickness exert a greater influence on the FEPE of HPGe detectors.

3.4. Application of the proposed integrated approach for the source activity corrections

Figure 5 shows that calculations of the source activity using the nominal DL differ significantly from the certified value. This discrepancy arises because the nominal DL provided by the manufacturer can change over time due to extended use. In contrast, the source activity estimated using the optimized DL closely matches the certified value, as indicated by the solid line – certified value of source activity at the time of counting, with much smaller deviation. This agreement is attributed to the ability of MCNP to re-estimate the DL and determine a corrected value that yields accurate source activity results.

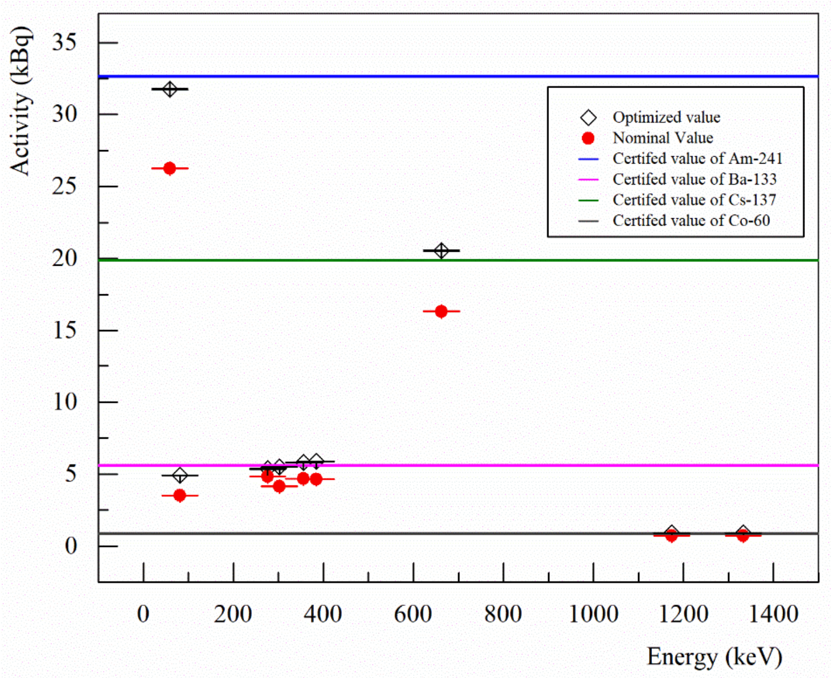

Fig. 5. MCNP estimated activities in comparison with certified values for the point source. (See color Figure on the journal website.)

Consequently, MCNP can be applied in various areas, including the re-estimation or correction of DL thickness and the accurate determination of source activity. Furthermore, it can be used to correct the FEPE of gamma spectrometers that have experienced extended use. The uncertainty in the calculated activity was determined by propagating the errors associated with the simulated FEPE and the measured net counting rate. The resulting activity uncertainties were found to be within 0.218 %.

4. Conclusion

This work demonstrates that long-term operation of HPGe detectors requires periodic re-evaluation of the DL to maintain accurate FEPE estimates. Using a combined experimental and MCNP simulation, we quantified the impact of DL growth on detector performance. We achieved strong agreement between measured and modeled efficiencies after incorporating an updated DL thickness, which increased up to seven times the initially determined value. These findings emphasize that relying solely on static manufacturer specifications can introduce significant systematic errors over time.

The presented methodology provides a practical framework for recalibrating aging detectors and can be widely applied to similar systems – other HPGe detectors: any HPGe detector, regardless of specific model, size, or n-type/p-type designation used for quantitative analysis. It is especially beneficial in fields like environmental monitoring, nuclear safety, or material characterization. We recommend a regular monitoring of DL thickness in HPGe detectors, particularly those in long-term use, and integrating Monte Carlo modeling into routine calibration procedures. This approach has the potential to extend detector lifespan, enhance measurement accuracy, and support long-term quality assurance in critical areas such as radiation protection, environmental monitoring, and nuclear applications. Furthermore, the method can be adapted to other detector types and simulation platforms, making it broadly applicable across laboratories and research facilities. Consequently, adopting this methodology ensures sustained measurement accuracy and reliability in long-term detector operations.

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РЕ-ХАРАКТЕРИЗАЦІЯ ДВОХ ПЛАНАРНИХ HPGe ДЕТЕКТОРІВ n-ТИПУ НА ОСНОВІ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ТА МОНТЕ-КАРЛО МОДЕЛЮВАННЯ

Точна гамма-спектрометрія з використанням детекторів з високочистого германію (HPGe) опирається на точне знання ефективності детектора, зокрема ефективності в піку повної енергії (FEPE), яка може знижуватися протягом тривалих періодів роботи через зростання неактивного мертвого шару (DL) детектора. Незважаючи на те, що ця проблема давно відома, корекція DL рідко враховується в детекторах з тривалим робочим циклом, а параметри, вказані виробником, часто приймаються як незмінні. У цьому дослідженні представлено комбінований підхід, що поєднує експериментальні вимірювання і Монте-Карло моделювання для ре-характеризації двох планарних HPGe детекторів n-типу – Sys1 та Sys2 – які перебувають у безперервній експлуатації майже три десятиліття. Хоча детектори мають практично ідентичні геометричні параметри, вони демонструють відмінності в роботі, що пояснюється головним чином варіаціями товщини DL. Було проведено вимірювання гамма-випромінювання з використанням сертифікованих точкових калібровочних джерел (59,5–1332,5 кеВ), а також виконано відповідне моделювання методом Монте-Карло (за допомогою програми MCNP5) для оцінки впливу зміни DL на FEPE та на активний об’єм детектора. У моделюванні було враховано геометричні фактори та ефекти поглинання. Результати дають змогу моделювати та коригувати втрати FEPE у детекторах з часом. Завдяки оптимізації товщини DL для Sys1 та Sys2 до 2,77 та 2,82 мм відповідно, відхилення між змодельованими та експериментальними FEPE було менше, ніж 5 %. Крім ядерного приладобудування, ця робота має значення для будь-якого застосування, що вимагає високоточної спектрометрії протягом тривалих експлуатаційних термінів, включаючи ядерну безпеку, аналіз радіоактивних відходів, моніторинг навколишнього середовища, радіаційну метрологію та ядерну криміналістику.

Ключові слова: детектор HPGe, ефективність у піку повної енергії, мертвий шар, MCNP, сертифіковані калібрувальні точкові джерела.

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