Quantitative radionuclide analysis protocol in a radiological and nuclear mobile laboratory

Protocolo de análise quantitativa de radionuclídeos em um laboratório radiológico e nuclear móvel

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ABSTRACT
This study establishes a quantitative analysis protocol of radionuclides in a radiological and nuclear mobile laboratory of the Brazilian Army's Institute of
Chemical, Biological, Radiological and Nuclear Defense. The gamma spectrometry technique was used, by a HPGe detector, to identify certified gamma-emitting radioactive sources (Am-241, Cs-137 and Co-60) present in a standard solution diluted in a Marinelli flask of 4L. Energy, resolution and efficiency calibration curves were determined using the LabFit software, for this detector, in the considered geometry. The results show to be satisfactory the linear adjustment (Channel versus Energy) of set points have been obtained experimentally which was confirmed by the determination coefficient achieved (R²=1). Besides that, it could be also verified that the exponential function was the mathematical model that best represented the answer of the HPGe detector energy resolution and that the mathematical adjustment options provided by LabFit which allowed to correlate the counting efficiency with the energy of each photopeak, despite the lack of a greater amount of energy. To define specific activities, the measurement errors between theoretical and experimental values were less than 4%, evidencing the reasonable responsiveness of the measurement system.

**Keywords:** protocol, gama spectrometry, mobile laboratory

**RESUMO**
Este trabalho estabelece um protocolo para análise quantitativa de radionuclídeos em um laboratório móvel radiológico e nuclear do Instituto de Defesa Química, Biológica, Radiológica e Nuclear do Exército Brasileiro. Utilizou-se a técnica da espectrometria gama, por meio de um detector HPGe, para identificação de fontes radioativas gama emissoras (Am-241, Cs-137 e Co-60) certificadas, presentes em uma solução padrão, diluída em um frasco de Marinelli de 4L. Determinaram-se as curvas de calibração em energia, resolução e eficiência, por meio do software LabFit, para o detector em tela, na geometria considerada. Os resultados sugerem que o ajuste linear ao conjunto de pontos (Canal versus Energia) obtidos experimentalmente demonstrou-se satisfatório, fato este comprovado pelo coeficiente de determinação alcançado (R²=1). Verificou-se também que a função exponencial foi o modelo matemático que melhor representou a resposta da resolução em energia do detector HPGe, e que as opções de ajustes matemáticos fornecidos pelo LabFit permitiram correlacionar a eficiência de contagem com a energia de cada fotopico, apesar da carência de uma quantidade maior de energias. Na determinação das atividades específicas, os erros de medição entre os valores teóricos e os experimentais foram menores do que 4%, evidenciando a boa capacidade de resposta do sistema de medidas.

**Palavras-chave:** protocolo, espectrometria gama, laboratório móvel

**1 INTRODUÇÃO**

A mobile radiological and nuclear laboratory consists of an installation, in the form of a container, capable of providing technical-scientific advice through the confirmation or identification, quickly and safely, of radiological and nuclear agents present in samples [1]. The objective is to verify the responses obtained by portable detectors used in the field, in order to better guide the actions of emergency response
groups [2, 3]. In this context, for the quantification of these radionuclides, there are several techniques used to evaluate their concentrations in samples from environmental systems [4, 5, 6].

Gamma spectrometry has proven to be an excellent alternative in the analysis of radiological agents in environmental samples, with suspicion of contamination, especially for providing a quick and non-destructive evaluation [7]. This technique is widespread and used by a wide network of laboratories that work in the quantitative analysis of radioactive materials in different types of samples [3, 6]. Among the main advantages of this technique in a mobile radiological and nuclear laboratory, the possibility of evaluating NORM in waste from water treatment and purification plants can be highlighted; the assessment of environmental disasters; and the control of radioactive materials in the border region [1, 3].

Hypothetically, a theoretical and experimental study of the main parameters to be considered in an analysis by gamma spectrometry is relevant in order to guarantee a good performance of the detectors and an increase in the reliability of its results, namely: the good calibration of the system measures; the counting efficiency by photon energy, considering that the exact determination of the counting efficiency is the key problem for gamma radiation measurements [6, 7]; the high resolution of the photopeak system; and a system that provides the calculation of the net photopeak area.

This analysis allows to verify in detail the best standardization of an experimental set-up capable of validating experimental results using certified standards; to minimize self-absorption by using standards with densities similar to the analyzed samples; and on this same methodological basis, to establish the masses of the analyzed samples, the radioactive patterns, as well as the spectra acquisition time; mainly in HPGe detectors, characterized by getting a better efficiency for this type of analysis [2, 3, 7].

Due to the need to estimate the radioprotection parameters responsible for guaranteeing the ALARA (As Low As Reasonably Achievable) principle, which establishes the necessary conditions to protect man from the effects caused by ionizing radiation [8], this paper aims to propose a protocol for quantitative radionuclide analysis in a mobile radiological and nuclear laboratory.
2 MATERIALS AND METHODS
2.1 EXPERIMENTAL APPARATUS

To establish the quantitative analysis protocol, it was used in this study a high resolution (25%) cylindrical and coaxial HPGe semiconductor detector, with Al window, 6.67 cm of external diameter and active volume of 40 cm³. The detector features a resolution of 1.87 keV for the 1.332 keV energy of Co-60 and 45% intrinsic relative efficiency. Unlike conventional Hyperpure Germanium detectors that lack a liquid nitrogen-based refrigeration system, the electromechanical refrigeration system was used, allowing the adjustment of the high voltage, which was 2,500 V in this case, coupled to a multichannel analyzer with 8,192 channels.

The experimental apparatus was set up in a mobile radiological and nuclear laboratory (LabMovel) of the Brazilian Army's Chemical, Biological, Radiological and Nuclear Defense Institute (IDQBRN) (Figure 1). The external structure of the LabMovel consists of a standard container (6.0 m x 2.45 m x 2.45 m) with a weight about 8,500 kg. The LabMovel can be transported by truck, aircraft, ship or train, and it can be placed in the open field without the aid of external machinery, due to its own system of self-levelling pistons [3]. The time for its deployment is less than 15 minutes, getting an autonomy up to 72 hours without refueling.

![Figure 1. Radiological and Nuclear Mobile Laboratory from IDQBRN.](image)

The laboratory environment conditions, such as temperature and relative humidity, were standardized. The detector was surrounded by a lead shield, with approximately 5 cm thick, and a thin internal surface made of copper and zinc, which makes the background radiation (BG) very low, together with the LabMovel steel structure, providing the measurement geometry with optimal conditions in relation to the
Furthermore, the Genie 2000 software – Gamma Acquisition & Analysis by Canberra® [9] was used for spectra acquisition and energy calibration. Figure 2 schematically illustrates the experimental apparatus used in this study.

Figure 2. Experimental apparatus used to identify radiological agents in samples.

2.2 ENERGY CALIBRATION

In order for a gamma spectrometry system to be able to identify radiological agents present in a sample, this system must initially be calibrated in terms of energy. In summary, this calibration process consists, in a first step, in the measurement of standard radionuclide sources, with representative energies of the energy range to be analyzed in the spectrum, and in a second moment, in obtaining the calibration curve, according to Equation 1 [10, 11].

\[ E = a_i + a_C C \]  

(1)

In Equation 1, variable E is the theoretical energy of the photopeak and variable C corresponds to the associated channel. For the energy calibration of the measurement system used in this study, some criteria were established that allowed to obtain greater reliability of the results: quantity of sample used in the analysis, use of certified standards (properly adequate for the energy ranges in this study), dilution of the patterns directly in matrices with densities approximately equal to the densities of the analyzed samples, standardization of the counting geometry (positioning in the detector) and the counting time [6, 11].

A liquid radioactive standard with 0.1 mol/L of HCl solution was used, with a mass \( M_s \) equal to 2.645070 g, containing Am-241, Cs-137 and Co- 60. This standard
was certified by the Institute of Radioprotection and Dosimetry (IRD/CNEN), with activities 16.047 kBq/g; 12.581 kBq/g and 16.693 kBq/g, respectively, with reference date on 12/01/2016. The radionuclides in question have well-defined energy spectra, allowing for a good count statistic to be obtained, and consequently, an energy calibration curve that efficiently adjusts to the obtained points [6, 8, 10].

For the proposed methodology, the liquid radioactive standard was diluted in 4 L of HNO3 1% (v / v), with 0.14 mol / L. The sample holder (Marinelli) was used for the packaging of the final solution obtained. [6, 9, 10, 12]. According to Figure 3, the Marinelli dimensions are: 7.8 cm of internal diameter; 17.8 cm outside diameter; height of 16.0 cm; and thickness of 1 mm. Figure 4 illustrates the measurement scheme using the sample holder.

![Figure 3. Sample holder (Marinelli).](image)

![Figure 4. a) on the left – measurement scheme using the Marinelli; b) on the right – measurement set used in the experiment of this study.](image)

In the spectra acquisition, the 59.5409 keV energy was used for Am-241, with 35.94% emission probability (γ%). Similarly, for Cs-137, the 661.6570 keV energy (γ% = 84.99%) was adopted and for Co-60, it was used the 1173.228 (γ% = 99.85%) and 1332.4920 keV energies (γ% = 99.9826%) [10].
For construction of the energy calibration curve, the least squares method was used, with the aid of the LabFit software. Thus, the calibration line was obtained, relating the values of Energy (E), in keV, relative to the liquid radioactive standard, with the associated channel (C), observed in the Genie 2000 program, according to the correlation presented in Equation 1.

2.3 ENERGY RESOLUTION CALIBRATION

The energy resolution is calculated in relation to the measure of the width of the photopeak at half of the maximum height (FWHM - Full Width at Half Maximum). In this case, it is considered that the pulse height tends to a normal distribution around an average value, being considered the most representative parameter to define the response function of the detector [10]. The energy resolution value is calculated by Equation 2 [11, 12].

\[
R(\%) = \frac{FWHM}{E} \cdot 100\% 
\]  

(2)

In Equation 2, variable R is the energy resolution; FWHM is the measure of the photopeak width at half of the maximum height, acquired directly by the spectrum obtained in the Genie 2000 program; and E is the theoretical energy of the photopeak. Thus, the smaller the variable R value, the better the system's energy resolution; so that closer energies can be separated. System interferences, such as electronic noise and low energy photons influence the photopeak broadening decreasing the resolution [10].

In this case, for each photopeak present in the liquid radioactive standard, it was calculated the value of the resolution in associated energy, according to Equation 2. In a similar way to the procedure adopted in the construction of the energy calibration, it was used the LabFit software to fit the resolution calibration curve in order to achieve the best mathematical model to the set of experimentally obtained points.

2.4 EFFICIENCY CALIBRATION

2.4.1 Efficiency Curve

The graph representing the efficiency curves has the counting efficiencies as a parameter, determined as a function of the gamma-emitting radionuclide, and the characteristic energies [10]. These curves are essential for a quantitative analysis, being the starting point in determining the efficiencies of radionuclide counts. Based on this
fact, it is possible to obtain the specific activities of radiological agents to be identified in sources from environmental matrices [11].

To acquire the efficiency calibration curve, the least squares method was used, also with the aid of LabFit, to build a mathematical model that relates the efficiency values ($\varepsilon$) with the different (theoretical) energies, $E$, in keV, relative to the liquid radioactive pattern. In this specific case, this software becomes an important optimization tool, helping to find a suitable mathematical function for use in a radioactive pattern characterized by low energies. In this program, adjustments are made through non-linear regression, applied iteratively, until a convergence criterion is satisfied [12].

2.4.2 Calculation of Theoretical Efficiency

In terms of comparison with the efficiency ($\varepsilon$) achieved by the mathematical model proposed by LabFit, the calculation of the theoretical efficiency of the specific energies was performed, for each radionuclide present in the radioactive standard described in the previous item, based on Equation 3 [9].

$$
\varepsilon_{\text{teo}} = \left[ \frac{S}{\left(A_0 e^{-\lambda t}\right) T \gamma} \right]
$$

In Equation 3, variable $\varepsilon_{\text{teo}}$ consists of the theoretical counting efficiency; $S$ is the net area of the spectrum, experimentally determined in counts; $A_0$ is the initial (theoretical) specific activity (kBq/g) of the radionuclide (provided by the IRD certificate); $T$ is count time (s); $\gamma$ is the gamma abundance of radionuclides present in the liquid radioactive pattern, for the considered energy; $\lambda$ is the decay constant of each radionuclide; and $t$ is the elapsed time (s) between the reference date and the spectrum acquisition date.

For the net area analysis ($S$) of the spectrum, which physically represents the number of pulses per second, referring to each photopic of interest, the background radiation was initially measured in order to subtract the value relative to the radioactivity level of the environment in which the radioactive pattern counts are being performed. For the counting of this background radiation, it was used the same geometry in the counting of the liquid sample (empty Marinelli) [6]. These counts also complied in the same time like the sample count. At the end, the BG count was subtracted from the analyzed sample count, and thus calculating the net value of the photopic area, according to Equation 4 [9, 13]:

$$
S_{\text{net}} = S - S_{\text{BG}}
$$
where $i$ is the region of interest (ROI) from the initial channel of the photopeak area; $f$ is the ROI of the final channel of the photopeak area; $Xa$ is the (gross) count in each channel; and BG is the background radiation count [11].

2.4.3 Calculation of radionuclide activities present in the liquid radioactive pattern

For the specific activities calculations, it was used the Equation 5, suggested by the International Atomic Energy Agency (IAEA) [9].

$$A_{\exp} = \left[ \frac{S}{\varepsilon \cdot T \cdot \gamma \cdot M_i} \right]$$

In Equation 5, $A_{\exp}$ consists of the specific activity (kBq/g), calculated for a given photopeak; $\varepsilon$ is the counting efficiency, determined by the efficiency calibration curve; $M_i$ is the mass (g) of the liquid radioactive standard sample; and the other terms, according to the description presented in Equation 3.

Finally, the spectra obtained were analyzed and the counting rate of each photopeak of interest was determined. These analyzes allowed us to obtain the three calibration curves mentioned above, for the geometry used. Indeed, Table 1 summarizes the data necessary for the calibration of the measurement system adopted in this study.

<table>
<thead>
<tr>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting time ($T$)</td>
</tr>
<tr>
<td>Number of counts</td>
</tr>
<tr>
<td>Standard certificate date</td>
</tr>
<tr>
<td>Spectrum acquisition date</td>
</tr>
<tr>
<td>Elapsed time ($t$)</td>
</tr>
<tr>
<td>The liquid radioactive standard mass ($M_i$)</td>
</tr>
</tbody>
</table>

3 RESULTS

3.1 ENERGY CALIBRATION CURVE

Figure 5 shows the calibration curve obtained for the HPGe detector used in this study, based on the liquid radioactive standard containing Am-241 ($E_\gamma = 59.5409$ keV); Cs-137 ($E_\gamma = 661.6570$ keV); and Co-60 ($E_\gamma = 1173.2280$ keV and $1332.4920$ keV). It is noteworthy that, for the construction of this curve, and for the other stages of this study,
the sample counting was performed in 30 h, and the spectrum was acquired on 06.14.2021.

**Figure 5. Energy Calibration Curve for HPGe with MCA 8192 channels.**

Based on Figure 5, from the analysis of the spectrum, obtained in the Genie 2000 software, referring to the sample containing the liquid radioactive standard, the mathematical adjustment to the set of points obtained was performed in LabFit. For a total number of 4 measurements, related to the energies used in the calibration of the measurement system, the linear adjustment proved to be satisfactory, since the value of the determination coefficient, \( R^2 \), corresponds to the unit value (\( R^2 = 1 \)). In this figure, the coefficients of the calibration line are also presented, showing the mathematical model proposed for an energy range varying from values close to 0 to approximately 1.500 keV. The parameters obtained for the HPGe detector from the mobile radiological and nuclear laboratory in IDQBRN showed that the measurement system has a good energy calibration, thus allowing the realization of the other experimental measurements steps.

3.2 RESOLUTION CALIBRATION CURVE

Table 2 presents the resolution (R%), calculated based on Equation 2, for the photopeak (E) of each radionuclide present in the liquid radioactive standard (Am-241, Cs-137 and Co-60).
Additionally, based on the data in Table 2, the mathematical model that presents the best fit to the set of points obtained was fitted in LabFit. Indeed, Figure 6 shows the resolution behavior (R%) in energy (E) for the HPGe detector from IDQBRN's LabMovel.

Thus, based on Figure 6, it is verified the resolution behavior (R%) as a function of energy (E) is defined by an exponential function, according to Equation 6, defined by LabFit:

\[ R = c_1 \exp \left( \frac{(E - c_2)^2}{c_3} \right) \]  

(6)

where the coefficients \( c_1, c_2 \) and \( c_3 \) of the equation proposed by the LabFit have respectively the following values: 0.2486E+01; 0.2826E+04; -0.1288E+08.
Based on these results, the mathematical model that correlates the resolution (R\%) and the photopeak energy (E) proved to be satisfactory, as the coefficient of determination achieved was equal to unity (R^2=1). Furthermore, it is also verified that the resolution increases with increasing energy, which allows defining a response function of the detector used in this study for the measurements performed. Nevertheless, it is noteworthy that this magnitude is an intrinsic characteristic of the detector. Besides, it can also be observed that the behavior between the physical properties indicated is acceptable from a theoretical point of view [10, 14], since detectors based on Germanium Hiperpuro have the best ability to discriminate energy ranges, which provides and justifies its better resolution, as demonstrated by the results obtained in this research.

3.3 EFFICIENCY CALIBRATION CURVE

Figure 7 shows the energy efficiency curve obtained for the HPGe detector from IDQBRN’s LabMovel, used in this work.

![Efficiency Calibration Curve](image)

The adjustment of the curve shown on Figure 7 was also performed in LabFit, making it possible to establish the parameters used in the correction of counting efficiencies. With these parameters obtained, Equation 7 was deduced in this program, allowing to calculate the efficiencies of counts adjusted for the different photopeaks used.
Based on this, it is possible to calculate the radionuclides activities present in any kind of sample.

\[
\varepsilon = \left[ \frac{1}{p_1 + p_2 E + p_3 E^4} \right] 
\]

(7)

In Equation (7), variable \( \varepsilon \) is the counting efficiency; \( E \) is the energy of interest for a particular radioactive element present in any sample; and the coefficients, \( p_1, p_2 \) and \( p_3 \), proposed by the LabFit, were respectively: -0.8039E+02; 0.3239E+00; and 0.1988E+05.

With the results for efficiency, it was also observed that the curve fitting to the 4 (four) points obtained experimentally proved to be satisfactory, since the determination coefficient was properly adjusted, as can be seen on Figure 7, with a value very close to the unit value (\( R^2 = 0.9980845 \)). The mathematical model proposed by Equation 7 comprehends low and high energies, thus characterizing the curve established for the HPGe detector from the IDQBRN’s LabMovel, with a more representative agreement, of the calculated data with the experimental data, observed for higher energies, as verified in the figure above.

Despite the lack of a liquid radioactive pattern that presented a greater amount of energy, especially in the low energy region, there are minimal discrepancies between theoretical and experimental values. This can be explained by the good resolution in energy attributed to semiconductor detectors and their low efficiency, promoting a lower sensitivity to interference in the range of energies below 100 keV, where the effects related to characteristic X-rays, the Compton effect and to electronic noise predominate [6, 9].

Furthermore, it can also be seen that the polynomial adjustment for efficiency did not generate any satisfactory result, due to the low energy pattern used. In this context, the equation proposed by Labfit (Equation 7) demonstrates the importance of using mathematical software that provide other adjustment options for these cases.

Based on this result for energy efficiency, we compared the value of \( \varepsilon \), from LabFit, and the \( \varepsilon_{\text{theo}} \) value, given by Equation 3, in order to verify the agreement of these results, as described in Table 3:
Table 3. Comparison between the efficiencies, theoretical and LabFit values.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Energy (keV)</th>
<th>$\varepsilon_{\text{teo}}$ (%)</th>
<th>$\varepsilon_{\text{LabFit}}$ (%)</th>
<th>Measurement error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241</td>
<td>59.5409</td>
<td>0.37</td>
<td>0.37</td>
<td>0.00</td>
</tr>
<tr>
<td>Cs-137</td>
<td>661.6570</td>
<td>0.61</td>
<td>0.61</td>
<td>0.00</td>
</tr>
<tr>
<td>Co-60</td>
<td>1173.2280</td>
<td>0.31</td>
<td>0.32</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>1332.4920</td>
<td>0.28</td>
<td>0.27</td>
<td>0.01</td>
</tr>
</tbody>
</table>

In view of the results presented in Table 3, there is a satisfactory agreement between the theoretical efficiency ($\varepsilon_{\text{teo}}$) and that calculated by LabFit ($\varepsilon_{\text{LabFit}}$), for all to energies relative to the radionuclides present in the sample containing the liquid radioactive standard. The measurement error between these efficiencies is equal to or less than 0.01%, showing that the mathematical model proposed by Equation 7 is adequate to correlate the efficiency ($\varepsilon$) and energy (E) of each photopeak. Furthermore, these results also denote the stability and reliability of the measurement system used in the protocol proposed in this study.

3.4 THE LIQUID RADIOACTIVE STANDARD ACTIVITIES

Confirming the methodological procedure proposed in this study, in order to analyze the level of accuracy in the calculations of specific activities, the response of the HPGe detector from the IDQBRN LabMovel was evaluated. Therefore, Table 4 presents the activity values of the certified standards, called reference activities ($A_{\text{ref}}$) and their values obtained experimentally as a function of the efficiency curve ($A_{\text{exp}}$), according to Equation 5. For Am-241 and Cs-137, the most abundant gamma photopeaks were used, and in the case of Co-60, the two energies with the highest emissions, according to IAEA TECDOC 619 recommendations [11].

Table 4. Specific activities of the Am-241, Cs-137 and Co-60 standard.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Energy (keV)</th>
<th>Emission (%)</th>
<th>$A_{\text{ref}}$ (Bq/g)</th>
<th>$A_{\text{exp}}$ (Bq/g)</th>
<th>Measurement error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Am-241</td>
<td>59.5400</td>
<td>36.92</td>
<td>16047.0000</td>
<td>16037.8709</td>
<td>0.06</td>
</tr>
<tr>
<td>Cs-137</td>
<td>661.6570</td>
<td>84.99</td>
<td>12581.0000</td>
<td>12619.0343</td>
<td>0.30</td>
</tr>
<tr>
<td>Co-60</td>
<td>1173.2280</td>
<td>99.85</td>
<td>16693.0000</td>
<td>17271.2687</td>
<td>3.46</td>
</tr>
<tr>
<td></td>
<td>1332.4920</td>
<td>99.98</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 4, the results found allow to verify that there was no significant difference between the reference values and the experimental values found for the liquid radioactive standard. In the case of Am-241 and Cs-137, the measurement error was less than 1%. For Co-60, the largest percentage error (associated with its higher energy) is
below 4%. In addition, the reduced background radiation (BG) in LabMovel also contributes to a better analysis in samples with low activity, since the environmental matrices are characterized by presenting quantities of radiological agents at levels of radioactive traces, suggesting that the measurement errors found may be considered negligible [6, 8].

Within this same context, it was also found that, as the energy values increase, the greater the error associated with the comparison of these measurements, suggesting that the greater the energy emitted by the radionuclide, the greater the relative deviation of the calculated activities. Furthermore, given the measurement errors found, it appears that, qualitatively, the measurement system of this study is stable and with a good responsiveness in the identification of radiological agents in samples, showing that the HPGe detector is suitable for studies involving gamma spectrometry of radionuclides present in environmental samples, with suspected contamination [2, 6, 13].

4 CONCLUSION

The main results of this research showed that the adjustment to the set of experimentally obtained points proved to be satisfactory in the process of energy calibration. It could be seen by the determination coefficient achieved (R²=1), thus ensuring the completion of the other experimental steps of this research.

The study also allowed us to verify that the exponential function was the mathematical model that best represented the response of the energy resolution of the HPGe detector from the IDQBRN’s LabMovel. Additionally, with regard to the efficiency curve, despite the lack of a liquid radioactive standard that presented a greater amount of energy, especially in the low energy region, minimal measurement errors were found between the experimental values and the theoretical values, especially for the adjustment options provided by LabFit, which denotes the importance of using mathematical software in these cases.

Another relevant result, as result of this study, is related with the determining the specific activities of radionuclides (Am-241, Cs-137 and Co-60), present in the sample containing the liquid radioactive standard. It could been no discrepancies in the concentration values, since the largest measurement error is less than 4%, referring to the highest energy photopeak of Co-60. In this context, the results obtained in the present study suggest that the HPGe detector is the most suitable for research involving gamma spectrometry of radionuclides present in samples with evidence of contamination.
In this way, the research shows, for studies involving gamma spectrometry, with the well-defined characterization of the ionizing radiation source, the methodology applied in systems that use high-resolution detectors allows verifying compliance with standards regarding the identification of radiological agents present in samples, as well as the influence of effective instrumentation on measurement processes.

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