BRAZILIAN JOURNAL OF RADIATION SCIENCES

doi.org/10.15392/2319-0612.2024.2641
2024, 12(4A) | 01-11 | e2641
Submitted: 2024-08-24
Accepted: 2025-02-20

Experimental Validation of the LabSOCS Detector Efficiency Simulation

Zahn*, G. S.; Genezini, F. A.

IPEN-CNEN/SP, Av. Lineu Prestes, 2242, São Paulo, SP - 05508-000.

Correspondence: gzahn@ipen.br

Abstract: The precise knowledge of the detection efficiency for gamma ray spectrometers is often of paramount importance, and its experimental determination can be both time-consuming and challenging, especially for complex geometries and/or extensive sources. A common solution for that is the use of Monte Carlo simulations, and some companies have developed commercial solutions. In the present work, the accuracy of the efficiency values determined by Mirion Industries' LabSOCS detection efficiency simulator was assessed by determining the activities of point sources measured under five distinct geometries, and comparing the results to the certified activity values. The results show that, while the software delivers reasonably reliable results, it tends to overestimate the efficiency, and special care may have to be taken with the precision of the geometrical measurements.

Keywords: HPGe detector efficiency, Monte Carlo simulation, LabSOCS, experimental validation.

doi.org/10.15392/2319-0612.2024.2641
2024, 12(4A) | 01-11 | e2641
Submitted: 2024-08-24
Accepted: 2025-02-20

Validação Experimental do Software de Simulação de Eficiência de Detectores LabSOCS

Resumo: O conhecimento preciso da eficiência de detecção é muitas vezes essencial em experimentos de espectrometria gama e sua determinação pode ser tanto demorada como desafiadora, especialmente em casos em que a fonte radioativa é extensa ou a geometria de detecção é mais complexa. Uma solução comum para estes problemas é o uso de simulações de Monte Carlo e várias soluções comerciais podem ser encontradas. No presente trabalho, a precisão dos valores de eficiência calculados pelo software comercial LabSOCS (Mirion Industries) foi avaliada por meio da comparação das atividades calculadas para fontes pontuais calibradas sob cinco geometrias distintas. Os resultados mostram que o software produz valores aceitáveis de eficiência, ele tende a superestimar a eficiência; além disso, ficou claro que é necessário extremo cuidado na determinação precisa da geometria.

Palavras-chave: eficiência de detector HPGe, simulação de Monte Carlo, LabSOCS, validação.

1. INTRODUCTION

In gamma spectroscopy measurements, the precise knowledge of the detection efficiency is often of paramount importance. On the other hand, while the experimental determination of the energy calibration of a given detector is a very quick and simple task, the experimental determination of the efficiency calibration can be both time-consuming and challenging, especially for sources that can't be treated as point-like [1].

As an answer to this problem, the use of Monte Carlo simulations have been a growing trend [2-4], and some companies have developed commercial solutions -- one such implementation that has found widespread use is ISOCS/LabSOCS, developed by Mirion [5], which is offered as an optional package for detectors of this manufacturer -- while ISOCS is a more general approach intended for *in situ* measurements, LabSOCS is a simpler implementation aimed towards measurements performed in a laboratory [6].

The manufacturer itself has published two articles for validating the LabSOCS efficiencies [6,7], both comparing the certificate activity of radioactive sources with the ones obtained using the LabSOCS efficiency calibration, for several distinct detection geometries – but no point-like sources. In both cases, the results agreed to the expected values, with reported biases around 4-6% - and an important warning is issued about sources where coincidence summing could interfere in the results. Looking at independent validations, several researchers not affiliated with Mirion/Canberra have published works aiming to assess the precision and reliability of the LabSOCS efficiencies [8-11], mainly for environmental and volumetric samples, all of them obtaining results that deviate from the expected values by 2-12%. Njinga and Tshivhase [8] reinforce that the precision of dimension measurements may strongly undermine the efficiency values; Stanić *et al.* obtained results within 10% of the expected values, but stress that in the energy range below 500 keV the software gave deviations from expected results, and state that other simulation codes should be tested; Suárez-Navarro *et al.* [10] performed tests on cement samples and obtained activity results with relative errors between 2.6% and 11.6% - it should be noted, also, that in their work there's a clear trend for activity values being underestimated by the software, indicating an overestimation of the efficiency; Barba-Lobo *et al.* [11] expanded that study for several extensive geometries, obtaining efficiency results that ranged between -12.4% and 10.8% of the experimental values. It should be noted, though, that none of the works found in the literature study the LabSOCS efficiencies for point sources, which – because of its simplicity – may be a better way to test the simulation of the intrinsic detector efficiency, and not of the propagation of radiation through distinct media.

In the present work, the accuracy of the efficiency values determined by LabSOCS were assessed by determining the activities of point sources measured under five distinct geometries and comparing the results to the certified activity values.

2. MATERIALS AND METHODS

Measurements were performed using a Canberra GX4018 XtRA HPGe detector with 40% nominal relative efficiency and a carbon composite window which was characterized at the factory, so that the LabSOCS efficiency software can be used with confidence. In order to assess the efficiency calculations both at low and high energies, the calibrated sources shown in Table 1 were used. Moreover, to verify the geometrical corrections, measurements were performed at distinct distances from the detector, and finally two known absorbers were placed between the source and the detector in some measurements.

Table 1: Radioactive sources used in the efficiency validation measurements with their activities on the date and time of the measurement, the main gamma-ray emission and the provenance of the source.

Nuclide	Activity (kBq)	Main γ (keV)	Provenance	Assay Date
Am-241	25.0 ± 0.3	59.54	IRD	19/06/2009
Co-60	1.356 ± 0.014	1173.24	IRD	02/10/2015
Ba-133	8.71 ± 0.09	356	IAEA	05/10/2015
Eu-152	77.9 ± 1.2	344	IPEN	01/02/1992
Eu-152a	1.96 ± 0.03	344	IRD	01/09/1997

[a.] As the 77.9 kBq source was of too high intensity to be used directly in front of the detector (position P1), a lower intensity one was used for this position, only.

All the spectra were analyzed using Canberra's Genie2000 software [12], and each of the geometries was carefully measured using either a vernier caliper with 0.1 mm resolution for the distances or a micrometer with 0.01 mm resolution for the thicknesses, and the source-detector distances and absorber thicknesses were entered into the LabSOCS geometry composer; also, the point sources had their internal geometry considered, and were simulated as thin (0.01 mm) discs with 1 mm diameter. The absorbers used were:

- A 3.68 mm-thick teflon cover (*teflon*);
- A 1.30 mm-thick acrylic source holder (*holder*);
- A 0.38 mm-thick stainless steel source holder (*steel*).

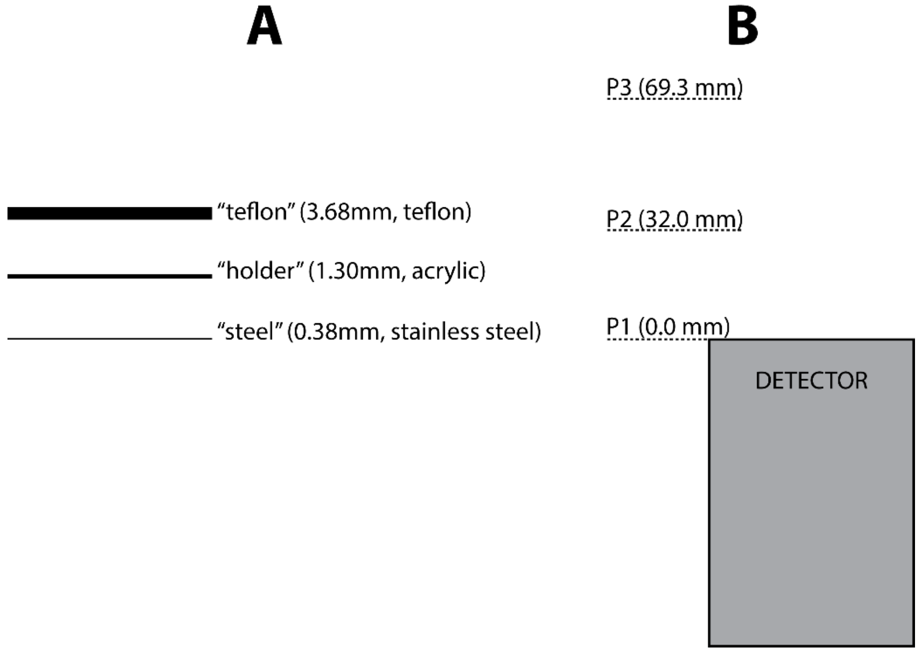
Measurements were taken at three distinct positions, and it should be noted that in all measurements performed in P2 and P3 the *holder* absorber was used. Fig. 1 shows a schematic drawing of the absorbers and irradiation positions.

P1. With the source placed directly in the face of the detector (or on top of the absorber, which was then placed directly in the detector);

P2. With the source placed at 32.0 mm from the face of the detector; and

P3. With the source placed at 69.3 mm from the face of the detector.

Figure 1: Schematic drawing of the absorbers used (A) and of the measurement positions (B).



With these data, the LabSOCS software performs a Monte Carlo simulation to determine the detection efficiency of the system for a series of predefined energies; as the Genie-2000 software has several options for the interpolation of these points, the internal "empirical" function was used – the whole calibration and interpolation procedure is very well described in the Genie-2000 Software Manual [12].

After the spectra were analyzed and the efficiencies were calculated, the activities of the radioactive sources were manually calculated using the transition intensities found in the IAEA ENSDF data [13] – the uncertainty propagation was performed using the partial derivatives method, described for instance in [14], and the uncertainties in the source activities (propagated from the certificates, and propagated taking into account the uncertainties in the half-lives – this usually adds up to around 2-4%) and the efficiency uncertainty estimated by the LabSOCS software (around 10% for lower energies, decreasing to 4-5% for higher ones).

For each determination, the z'-score (eq. 1) and relative error (eq. 2) were calculated (in both equations, *x* are the values, σ are the uncertainties and the subscripts *exp* and *ref* are for experimental and reference, respectively).

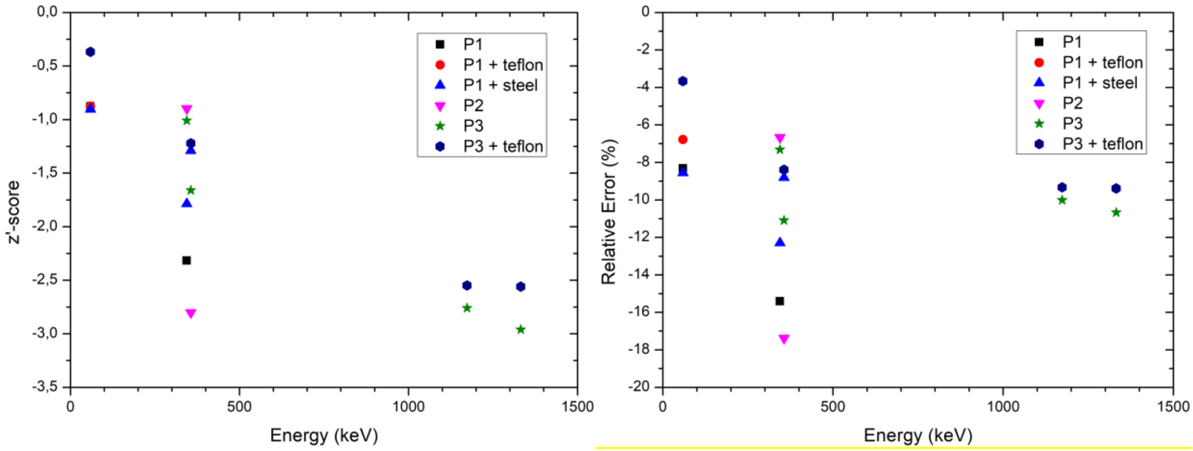
$$z' = \frac{x_{exp} - x_{ref}}{\sqrt{\sigma_{exp}^2 + \sigma_{ref}^2}} \quad [1]$$

$$RE = \frac{x_{exp} - x_{ref}}{x_{ref}} \quad [2]$$

3. RESULTS AND DISCUSSIONS

The z'-scores and relative errors determined for each measurement are presented in Fig. 2 -- for the ^{60}Co measurements the calculations were performed separately for each gamma transition, in order to assess possible discrepancies.

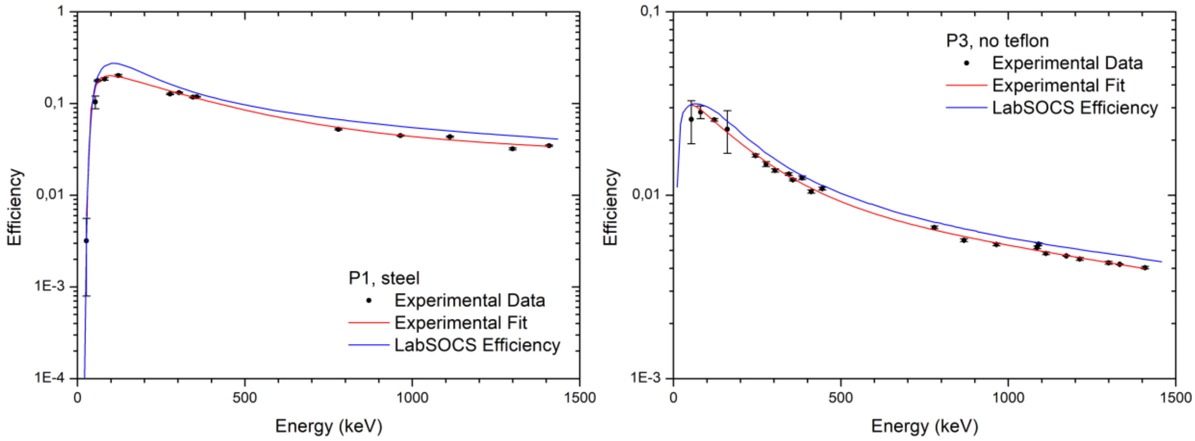
Figure 2: Z'-Scores (left) and relative errors (right) obtained for the distinct activity measurements.



While all experimental determinations resulted in z'-scores below 3 (i.e., results than can be considered statistically acceptable in a 99.7% significance level), it must be noted that all the activities determined experimentally were lower than the expected value, indicating a possible overestimation of the detection efficiency, agreeing with most of the findings in [10]. It must also be noted that, while for ^{241}Am the results were mainly OK (|z'-score| < 1, meaning they are within 1σ of the expected value), for ^{60}Co the results were generally not great (|z'-score| > 2, meaning that although they are compatible in a 99.7% confidence interval, they are not compatible if a stricter 95% interval is adopted).

A visual comparison of the efficiencies obtained experimentally to the values generated by LabSOCS for two distinct geometries is shown in Fig 3, and it shows clearly that the LabSOCS efficiencies are overestimated; moreover, it should be noted that for the P1 measurement the only thing standing between the source and the face of the detector is the steel absorber, whose thickness determination using the micrometer is rather straightforward, so the discrepancy can't be due to a measurement error.

Figure 3: Experimental efficiency compared to the LabSOCS simulation for position P1 with the steel absorber (left) and for P3, without the teflon absorber -- in both cases the red line shows the efficiency function described in [15] fitted to the experimental data, and the blue line shows the LabSOCS calculated efficiency.



Comparing the relative errors obtained in this measurement with the results found in the literature [6-11], although the latter were obtained exclusively for extense sources, most of the results presented here show relative errors (RE) in the same range as the ones reported (|RE|≤ 14%), with two exceptions: the 344 keV transition from ^{152}Eu in P1 (RE = -15.4%) and the 356 keV from ^{133}Ba in P2 (RE = -17.4%). This similarity of results seem to indicate that the source of the errors lie on the simulation of the detector itself, rather than on the propagation of radiation through extensive sources. Moreover, these results indicate that the use of the LabSOCS efficiencies should be acceptable for experiments where the uncertainties are larger, around 10% (for example, in environmental analyses), but extra care should be taken when dealing with lower uncertainty measurements as Neutron Activation Analysis (NAA), for example, where the total uncertainties may be lower than 1% [14].

Finally, in order to check for the sensitivity of the efficiency regarding the distance measurements, as suggested by [8], the source-detector distance in the simulation was increased by 1 mm (from 32 mm to 33 mm) for P2, and that resulted in a 2-3% reduction in the efficiency calculated by LabSOCS. This indicates that users should be aware that distances have to be measured very carefully, as the effect of a minimal difference on the efficiency values is quite noticeable.

4. CONCLUSIONS

The comparison of the certified activities of four radioactive sources with the results obtained experimentally using detection efficiencies calculated by the LabSOCS Monte-Carlo simulation software indicates that while the LabSOCS efficiencies tend to be overestimated, and there's indication that this effect could be larger at higher energies, the results were compatible with the expected ones within a 3σ interval. The relative errors were mostly below 10%, but in some cases they reached almost 20%, indicating that while the use of the LabSOCS efficiencies shouldn't pose a problem for measurements with an intrinsic higher uncertainty (as environmental analyses), extra care should be taken when using it with more delicate analyses.

Finally, it was shown that dimension measurements must be performed with extreme care, as minimal differences may implicate on significant changes in the resulting efficiency.

These results indicate that further validation measurements should be performed, and that in daily routine it is safer to perform at least one experimental validation measurement for every distinct geometry that is simulated.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

REFERENCES

[1] DOS SANTOS, R. M. Desenvolvimento de um método para obtenção da eficiência de detecção para detectores HPGe em medidas com fontes extensas, MSc. Dissertation, IPEN/USP, DOI 10.11606/D.85.2012.tde-24082012-162508, 2012

[2] HURTADO, S.; GARCIA-LEON, M.; GARCIA-TENORIA, R. Monte Carlo simulation of the response of a germanium detector for low-level spectrometry measurements using GEANT4, **Appl Radiat Isot**, v. 61, p. 139-143, 2004.

[3] BOSON, J.; GÖRAN, A.; JOHANSSON, L. A detailed investigation of HPGe detector response for improved Monte Carlo efficiency calculations, **Nucl. Instrum. Meth. Phys. Res A**, v. 587, p. 304—314, 2008.

[4] SUBERCAZE, A. *et al.* Effect of the geometrical parameters of an HPGe detector on efficiency calculations using Monte Carlo methods, **Nucl. Instrum. Meth. Phys. Res A**, v. 1039, 167096, 2022.

[5] ISOCS™ / LabSOCS™ Calibration Methodology, Available at: https://www.mirion.com/isocs. Access: 27/aug/2024..

[6] BRONSON, F. L. Validation of the accuracy of the LabSOCS software for mathematical efficiency calibration of Ge detectors for typical laboratory samples, **J Radioanal Nucl Chem**, v. 255, p. 137—141, 2003.

[7] STEWART, J. P.; GROFF, D. LabSOCS™ vs. Source-based gamma-ray detector efficiency comparisons for nuclear power plant geometries, *In:* Proceedings of the

48th Annual Radiobioassay & Radiochemical Measurements Conference, Knoxville, Tennessee, November 11-15, 2002.

[8] NJINGA, R.L.; TSHIVHASE, M. V. A Comparison of LabSOCS and Source-Based Full Energy Efficiency Generation in Measurements, **International Journal of Advanced Research**, v. 4, p. 1102—1107, 2016.

[9] STANIĆ, G. *et al.*, Angle vs. LabSOCS for HPGe efficiency calibration, **Nucl. Instrum. Methods Phys. Res. A**, v. 920, p. 81—87, 2019.

[10] SUÁREZ-NAVARRO, J.A. *et al.,* Gamma spectrometry and LabSOCS-calculated efficiency in the radiological characterization of quadrangular and cubic specimens of hardened Portland cement paste, **Rad. Phys and Chem.**, v. 171, 108709, 2020.

[11] BARBA-LOBO, A. *et al.,* Robustness of LabSOCS calculating Ge detector efficiency for the measurement of radionuclides, **Rad. Phys. Chem.**, v. 205, 110734, 2023.

[12] CANBERRA INDUSTRIES, Genie-2000 Spectroscopy System v.3.41 -- operations manual, Meriden, USA, 2012.

[13] Evaluated Nuclear Structure Data File (ENSDF), Available at: https://www-nds.iaea.org/relnsd/NdsEnsdf/QueryForm.html. Access 27/aug/2024.

[14] ZAHN, G. S. *et al.* Uncertainty Analysis in Comparative NAA Applied to Geological and Biological Matrices. *In*: PROCEEDINGS OF THE 2015 INAC, Santos, October 4-9, 2015.

[15] ZEVALLOS-CHÁVEZ, J. Y. *et al.* Study of the inactive layer of a germanium detector: experimental and Monte Carlo simulation treatment, PROCEEDINGS OF THE 2005 INTERNATIONAL NUCLEAR ATLANTIC CONFERENCE, Santos, 28 August to 2 September, 2005.

LICENSE