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Experimental Validation of the LabSOCS Detector Efficiency Simulation

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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].

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. Methodology

Measurements were performed using a 40% Canberra Extended Range HPGe with 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, calibrated sources of ^{241}Am ($E_\gamma = 59.54$ keV), ^{60}Co ($E_\gamma = 1173.24$ and 1332.51 keV), ^{133}Ba (main $E_\gamma = 356$ keV) and ^{152}Eu (main $E_\gamma = 344$ keV) were used (the activities ranged from 1.4 to 77 kBq). 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.

All the spectra were analyzed using Canberra's Genie2000 software [7], and each of the geometries was carefully measured using either a vernier caliper or a micrometer and 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.

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.

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 [8].

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* and for experimental and reference, respectively).

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

$$RE = \frac{x_{exp} - x_{ref}}{x_{ref}} \tag{2}$$

3. Results and Discussion

The z'-scores and relative errors determined for each measurement are presented in Fig. 1 – for the ^{60}Co measurements the calculations were performed separately for each gamma transition, in order to assess possible discrepancies.

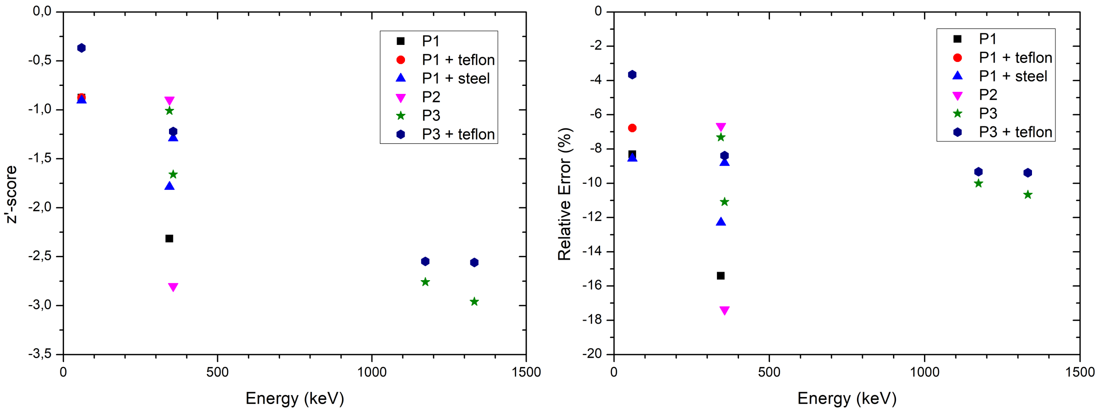

Figure 1: Z'Scores (left) and relative errors (right) obtained for the distinct activity measurements.

While all experimental determinations resulted in z'-scores below 3 (i.e., results than can be considered statistically acceptable), it must be noted that all the activities determined experimentally were lower than the expected value, indicating a possible overestimation of the detection efficiency. It must also be noted that, while for ^{241}Am the results were mainly OK ($|z' - score| < 1$), for ^{60}Co the results were generally not great ($|z' - score| > 2$).

A visual comparison of the efficiencies obtained experimentally to the values generated by LabSOCS for two distinct geometries is shown in Fig. 2, 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, which is quite easy to measure precisely using a micrometer, so the discrepancy is hardly due to a measurement error.

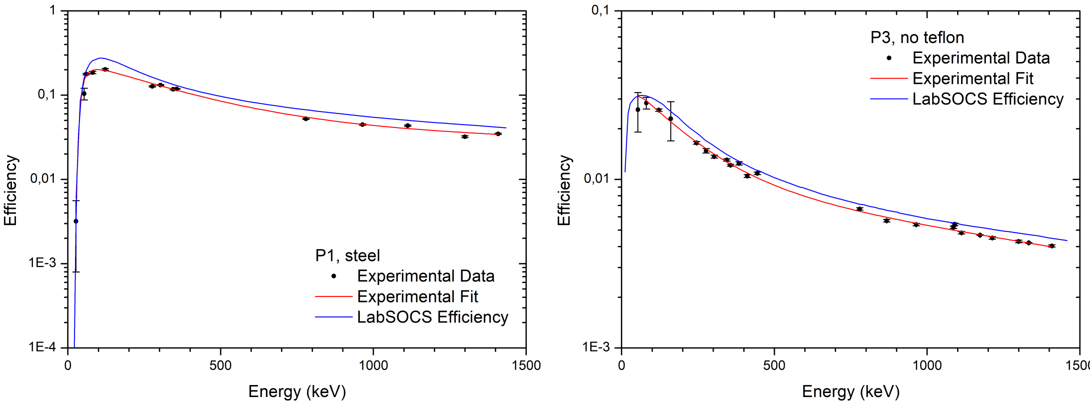

Figure 2: Experimental efficiency compared to the LabSOCS simulation for position P1 with the steel absorber (left) and for P3, without the teflon absorber – in both cases the red line shows the efficiency function described in [10] fitted to the experimental data, and the blue line shows the LabSOCS calculated efficiency.

As for the relative errors (RE), while for most measurements RE's were below 10%, in two measurements the RE's were much greater than that: ^{152}Eu in P1 ($RE = -15\%$) and ^{133}Ba in P2 ($RE = -17\%$). This indicates that the use of the LabSOCS efficiencies should be acceptable for experiments where the uncertainties are larger (for example, in environmental analyses), but extra care should be taken when dealing with lower uncertainty measurements as Neutron Activation Analysis (NAA), for example [9].

Finally, in order to check for the sensitivity of the efficiency regarding the distance measurements, the source-detector distance was increased by 1 mm (from 32 mm to 33 mm) in the simulations 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 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 3 σ interval. The relative errors were mostly below 10%, but in some cases it 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.

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