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Variability - Surface intensity distribution of large-area reference sources

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ABSTRACT

In this paper we present the impact of variability, a surface source parameter, on the efficiency evaluation of surface contamination monitors. This study was based on two source uniformity correction methodologies and data from real surface source distributions. Surface source intensity distribution has been changed by rearranging the cells (portions of the active area of each LARS) while keeping the same source uniformity value. Instrument efficiencies have been calculated for different sets of uniformities and variabilities. This study led to emphasize the importance of variability, a differential source intensity distribution parameter, over the uniformity, an integral source intensity distribution parameter, and reinforced the importance of the source uniformity correction procedure on the course of surface contamination monitor calibration.

1. Introduction

ISO 7503–3:2016 (ISO 7503-3, 2016) and ISO 8769:2016 (ISO 8769, 2016) are the standard documents regarding the calibration procedure of surface contamination monitor and the characteristics of reference sources used in these procedures, respectively. ISO 8769:22016 stresses the importance of large area reference sources (LARS) to meet some quality criteria to be used on the calibration procedures. The uniformity is one of these parameters that have deserved much attention along the years, which can be observed both by the number of papers or articles presented in literature (Burgess and Iles, 1983; Nähle and Kossert, 2012; Yamada et al., 2012; Ohshiro et al., 2016) as by the release of new guides, which also includes a change on its definition (ISO 8769, 2010). Nonetheless, the production of uniform LARS still stands as difficulty to overcome as there are still some reports on the existence of LARS that do not meet the 90% uniformity criteria (Vivolo and Potiens, 2010; Silva Junior et al., 2014). As an attempt to evaluate and overcome the bias introduced on surface contamination monitor efficiency due to the use of non-uniform LARS on calibration procedures, we have proposed a correction methodology (Silva Junior et al., 2020), based on MCNP5 (X-5 Monte Carlo Team, i, 2003) simulations. This proposal was compared to the methodology presented by NPL (Lee and Burgess, 2014) leading to similar results (Silva Junior et al., 2020). In the present paper we have used the methodology based on MCNP5 simulations to study the effectiveness of the uniformity parameter as an indispensable source criterion. The surface source intensity distribution of four beta emitting LARS has been redistributed along its active area keeping their original uniformity values unchanged. Correction factors were driven for every source distribution of each LARS. The attained results indicate that monitor efficiency estimates may deviate from the value it would be expected using a uniform source (100% uniformity value) by as much as 14% even for LARS meeting the 90% minimum uniformity criterion set by ISO 8769:2016. The deviation may be even larger for LARS not meeting the uniformity criterion. These deviations stress the importance on incorporating the correction factor methodology in radiation monitor calibration procedures.

2. Materials and methods

2.1. Correction factor methodologies

A correction factor methodology developed to cope with low uniformity values of large area beta reference sources, which was presented in a previous article (Silva Junior et al., 2020), was used along this work. It consists in applying a correction factor to a declared instrument efficiency value in order to get more exact estimate. The correction factor is

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Table 1
Experimental source uniformity data.

Nuclide Source	Uniformity (%)	Relative Standard Uncertainty (%)
^{14}C	50.20	0.40
^{99}Tc	90.66	0.04
^{36}Cl	84.44	0.05
^{90}Sr	91.18	0.02

obtained from simulations of the surface radiation monitor calibration procedure. In this procedure the monitor probe is placed over the center of a large area reference source and its efficiency is calculated from the ratio between its registered radiation counting rate and the surface radiation emission rate under the probe area. Simulations are performed to tally the detection efficiencies for two distinct LARS distributions: the uniform and the real one. The real one is taken as the experimental source emission rate distribution of the LARS under use, while the uniform distribution stands as the 100% uniformity value, which is the reference condition of the efficiency calculation methodology. The differences observed between simulated efficiencies are only due to the differences in source distribution representations. The correction factor is then obtained by the ratio between the uniform and real simulated efficiencies. The corrected instrument efficiency is calculated by multiplying the correction factor found to the uncorrected instrument efficiency driven from the experimental calibration. The previous work (Silva Junior et al., 2020) also compared its LARS uniformity correction methodology to the one proposed by NPL. Although the NPL methodology is presented in order to be applied to LARS with uniformity values of at least 90%, the comparison between correction factors driven from both methodologies shows that they led to similar results, even when NPL methodology is applied to LARS not meeting its application recomendation criteria. The NPL methodology is used here again in this work in order to keep it as a parallel reference.

2.2. Large area beta radiation sources

As the uniformity values of the LARS and both MCNP5 and NPL uniformity correction methodologies rely on surface emission distributions, data from the four β^- emitters (^{14}C, ^{99}Tc, ^{36}Cl and ^{90}Sr) rectangular, 100 mm × 150 mm, LARS used in our previous work (Silva Junior et al., 2020) have been used along the present one. Surface emission distributions were experimentally evaluated along 24 contiguous portions (cells) of the active area of each LARS, in a six columns and four rows matrix configuration. The procedure consisted in matching a 2 mm thick aluminium mask with a 25 mm × 25 mm square aperture over one of the cells. A detector, placed over the aperture in a fixed and centered relative position to the aperture, performed the radiation counting for a fixed period of time. The surface emission of the cell was obtained by the net radiation counting, i.e. after discharging the background radiation contribution. This procedure was repeated to each one of the 24 cells. Experimental data from these procedures led to the calculation of uniformity value for each LARS (Table 1) and to evaluation of their relative superficial radiation emission distributions through the histograms shown in Fig. 1.

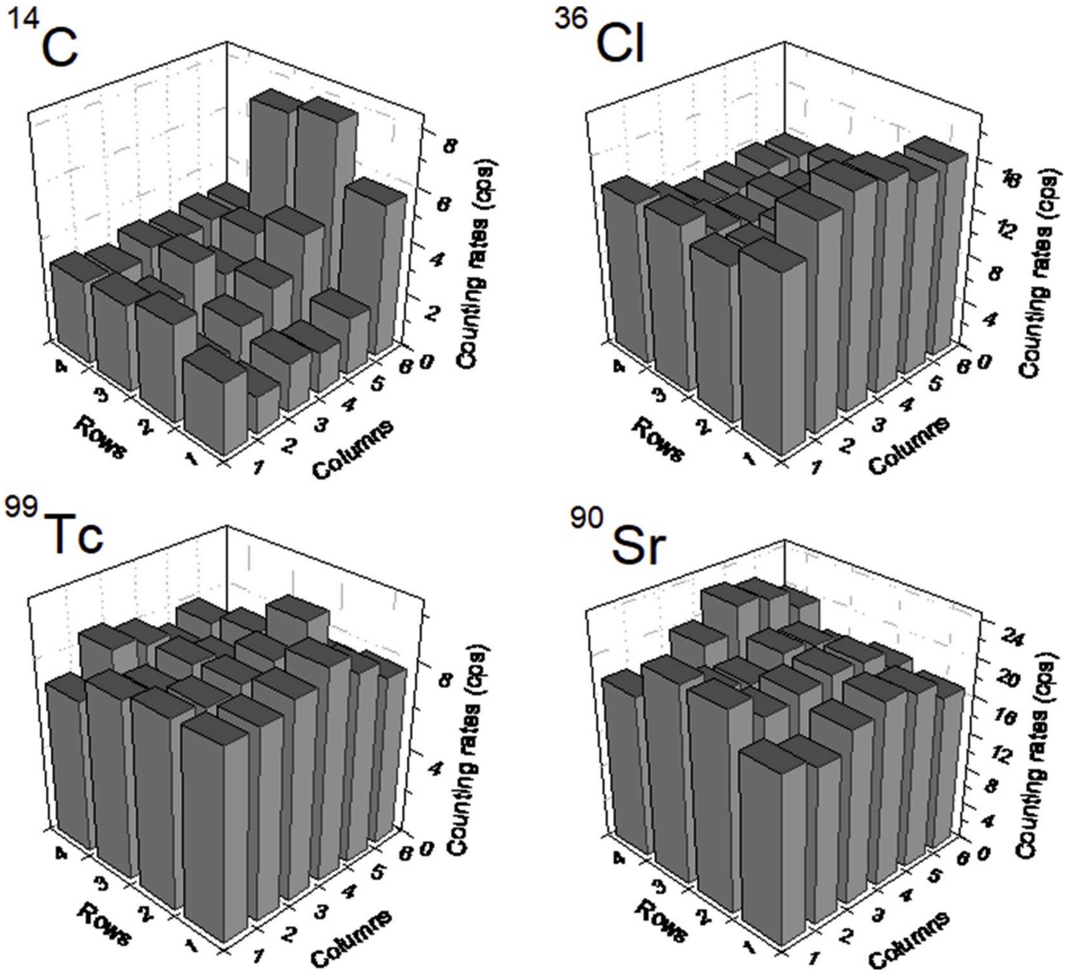

Fig. 1. Relative surface source intensity distributions of the ^{14}C, ^{99}Tc, ^{36}Cl and ^{90}Sr LARS.

Table 2
Instrument efficiency values and associated correction factors.

Nuclide	ε	CF	$\varepsilon_{corrected}$	$\Delta\varepsilon$
Source	(%)		(%)	(%)
^{14}C	20.2 ± 0.6	1.179	23.8 ±0.7	−15.2
^{99}Tc	38.0 ± 1.1	0.980	37.2 ±1.1	2.0
^{36}Cl	48.7 ± 1.3	1.074	52.3 ±1.4	−6.9
^{90}Sr	56.5 ± 1.5	0.987	55.8 ±1.5	1.3

2.3. Instrument efficiencies

The calibration efficiency of the radiation detection setup made of a Thermo FH40GX model monitor with a FHZ732GM model pancake probe, with a 4.44 cm diameter entrance window, was obtained in the previous work (Silva Junior et al., 2020) for all four large area beta reference sources. The calibration procedure consisted in placing the detector probe on an aluminium support, which stood next to the LARS, in such a way that the circular window of the probe, the circular aperture in the aluminium support and the center of the LARS active area were all properly aligned. The detection setup was run for a specific time in order to present an acceptable precision. The efficiency (ε) was then computed by the ratio between the net reading and the LARS emission rate of an area equivalent to probe window. In this procedure the source is taken as uniform, i.e. with an uniformity value of 100%. The instrument efficiencies were then evaluated taken into account the surface source distributions obtained in the mapping procedure described above. These corrected efficiencies were obtained by applying the correction factors driven from MCNP or NPL correction methodologies, which led to the same values as it has been stressed in the previous work (Silva Junior et al., 2020). The correspondence between both methodologies were observed for all data evaluated in this work and, therefore, there will be made no distinction between the methodologies used when presenting correction factor and corrected efficiency values. Table 2 shows the uncorrected efficiencies (ε) attributed to the instrument for each LARS calibration setup, the correction factors (CF) and corrected efficiencies ($\varepsilon_{corrected}$) obtained from both methodologies. It is also shown the differences on instrument efficiencies it would be observed if no correction had been applied ($\Delta\varepsilon$).

Correction Factor uncertainties are driven from the precision in stablishing the relative weight of the cells on surface source distribution. The instrument efficiency uncertainties are mainly due to the uncertainty on the LARS surface emission rate.

2.4. Variability - surface source distribution

Besides retrieving information about source uniformity, source mapping also retrieves information about source intensity distribution, which has not been treated as an important source parameter by ISO 8769:2016. Variability is defined herein as characteristics of the LARS

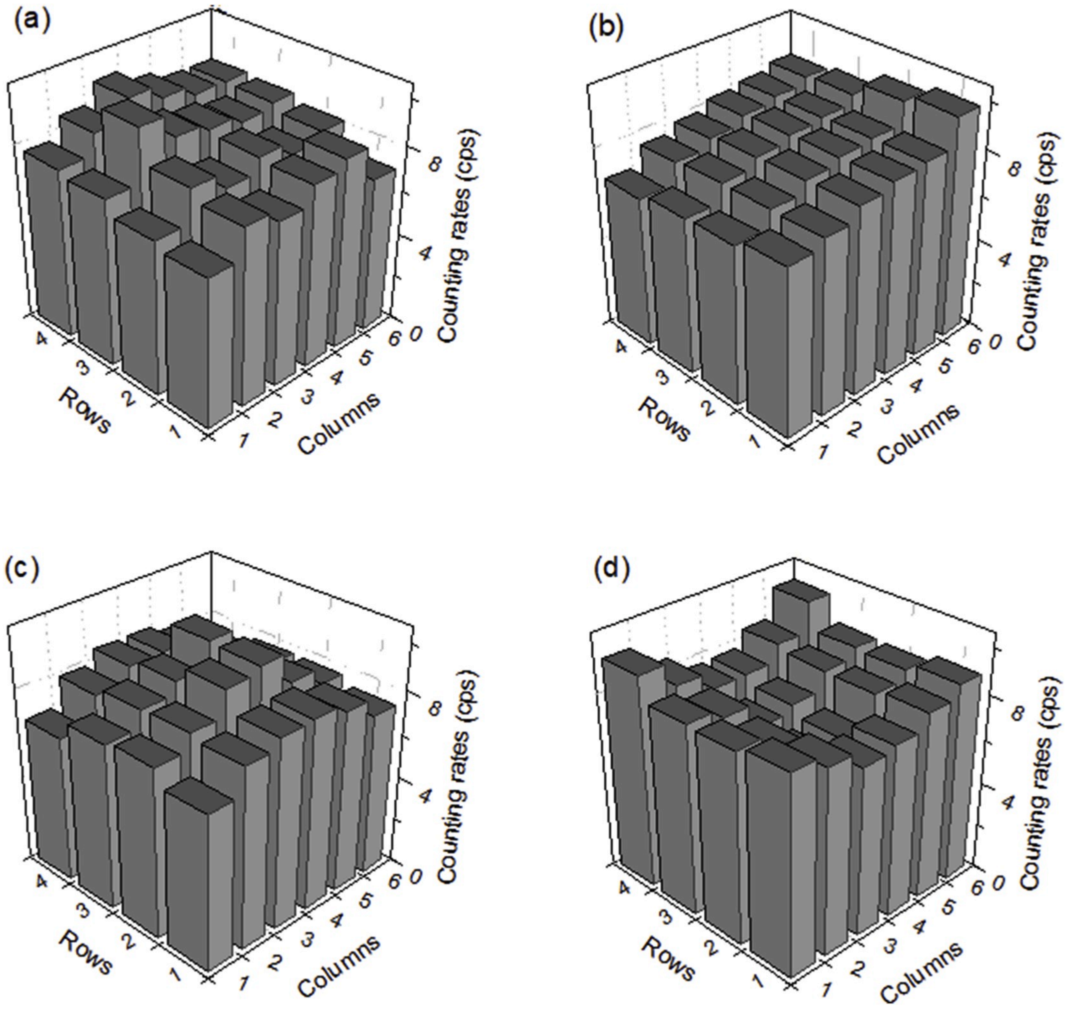

Fig. 2. ^{99}Tc Surface Source Distributions: (a) Original distribution; (b) Slope distribution; (c) Central distribution and (d) Marginal distribution.

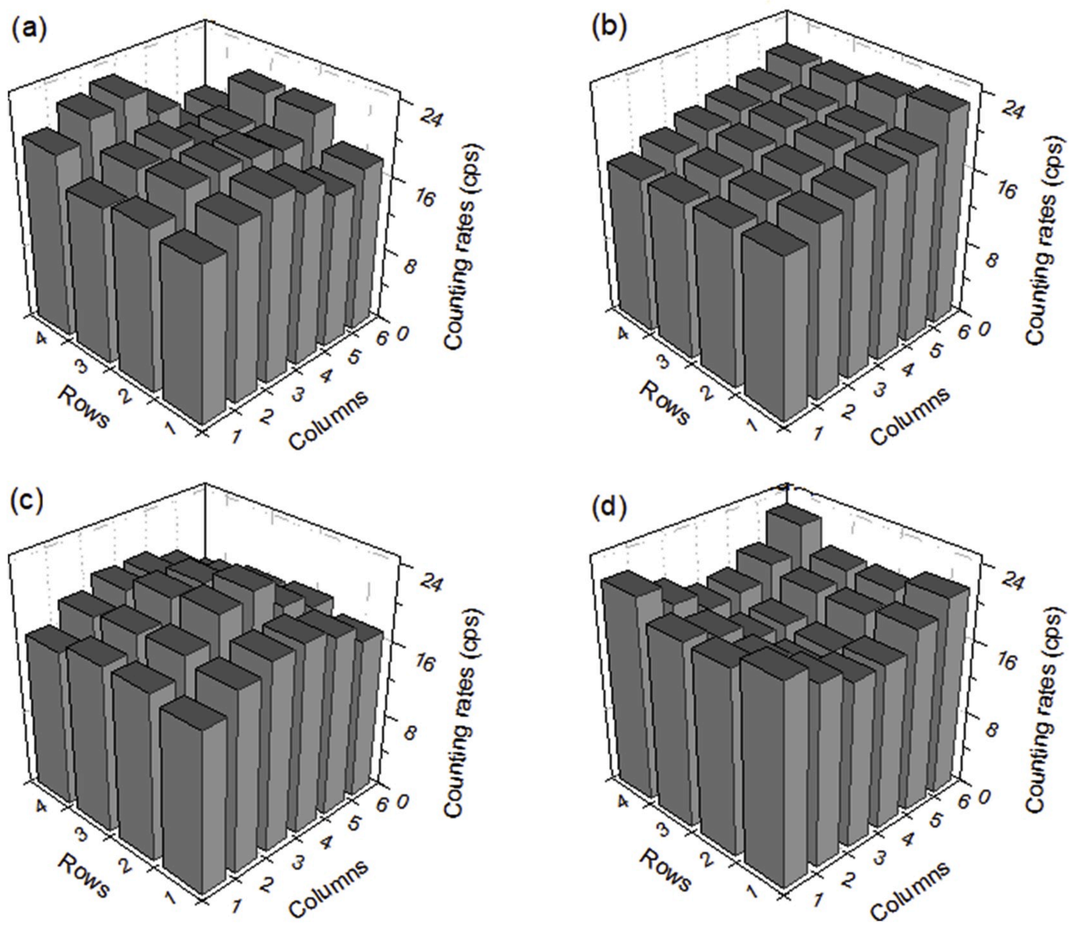

Fig. 3. ^{90}Sr Surface Source Distributions: (a) Original distribution; (b) Slope distribution; (c) Central distribution and (d) Marginal distribution.

associated with its surface source distribution. Variability, as uniformity, deals with surface source intensity distribution. However, while uniformity stands as an integral source intensity parameter, providing an indication on how much source distribution is equalized along the source active area, variability stands as a differential parameter, associated on how the source intensity is distributed along its active area. In order to evaluate the importance of source variability in the calibration procedure, the correction factor methodology has been used to estimate the efficiencies it would be retrieved from calibration procedures using sources with the same uniformity value, but different surface source intensity distributions. This was accomplished by rearranging the surface source intensity distribution of the large area beta reference sources in 3 other hypothetical fashions: (1) variation along the main axis (slope distribution); (2) concentration at its center (central distribution); (3) concentration at its corners (marginal distribution). Figs. 2 and 3 illustrates the variability idea by showing respectively the histograms of the surface source distributions of the ^{99}Tc and ^{90}Sr LARS for four surface source distributions: (a) Original experimental distribution, where the distribution of the cells emission intensities, obtained experimentally by mapping the sources, was maintained and the (b) Slope, (c) Central and (d) Marginal hypothetical distributions.

Table 3
^{99}Tc Sources variability study.

$\varepsilon_{corrected} = 37.2\%$

Distribution	CF	ε (%)	Δε (%)
Original	0.980	38.0	2.0
Slope	0.984	37.8	1.6
Central	0.880	42.3	13.6
Marginal	1.167	31.9	−14.3

Table 4
^{90}Sr Sources variability study.

$\varepsilon_{corrected} = 55.8\%$

Distribution	CF	ε (%)	Δε (%)
Original	0.987	56.5	1.3
Slope	0.994	56.1	0.6
Central	0.877	63.6	14.0
Marginal	1.144	48.8	−12.6

It shall be remembered that ^{99}Tc and ^{90}Sr LARS meet the ISO 8769:2016 uniformity criterion of the minimum 90% value and therefore they might be used in calibration procedures of surface contamination monitors. Tables 3 and 4 show the correction factor values (CF) obtained for each of the four emission distributions of both ^{99}Tc and ^{90}Sr sources shown in Figs. 2 and 3. It is also shown in this table, the uncorrected instrument efficiencies values (ε) it would be expected if the correction factors were not applied and the percentage differences ($\Delta\varepsilon$) over the corrected instrument efficiency values. As the Slope, Central and Marginal distributions are only hypothetical, the efficiencies the detector would be attributed using LARS with such variabilities were driven in a backward fashion, i.e., the corrected instrument efficiency of the original distribution was taken as the reference efficiency value.

It can be seen from Tables 3 and 4 that LARS, that a specific

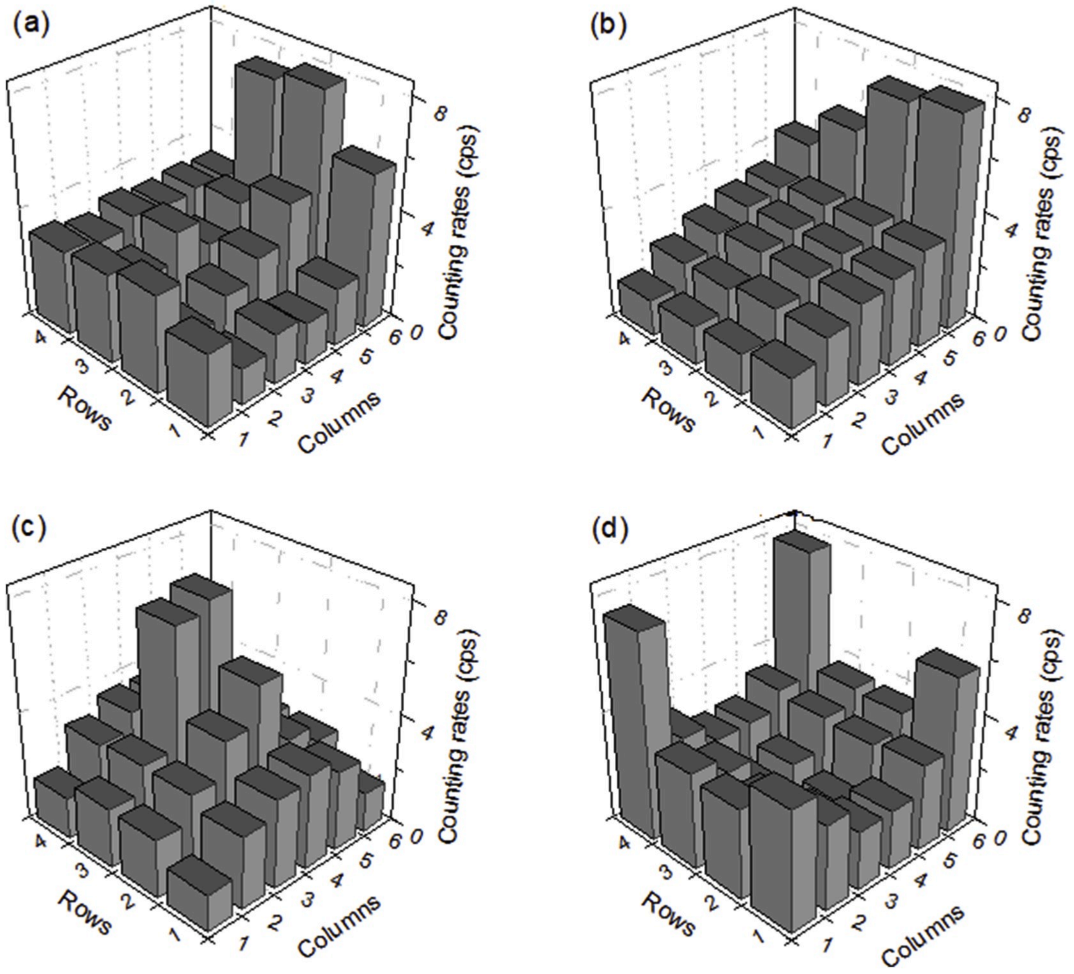

Fig. 4. ^{14}C Surface Source Distributions: (a) Original distribution; (b) Slope distribution; (c) Central distribution and (d) Marginal distribution.

radionuclide source, with a specific beta emission spectra, and a specific uniformity value, might lead to different instrument efficiency values if no correction had been applied (ε). Instrument efficiencies might be either overestimated (Central distribution) or underestimated (Marginal distribution), and present a variation from the reference value ($\Delta\varepsilon$) as large as 14% for source distributions with the same reference source uniformity value, and attaining the requirements of ISO 8769:2016. This 14% difference in efficiency is close to the value observed for the ^{14}C LARS (Table 2), which presents the uniformity far bellow ISO 8769:2016, 90% minimum value. Correction factor values, driven by applying the simulation methodology presented in this work, present a more pronounced correlation with the variability than with the uniformity. The variability study was further extended to the two other LARS, ^{14}C and ^{36}Cl that do not meet 90% minimum source uniformity criterion. Variability representations for ^{14}C and ^{36}Cl LARS are shown in Figs. 4 and 5 respectively, while Tables 5 and 6 present correction factors and efficiencies data from uniformity correction methodologies.

The application of the instrument efficiency correction methodology to the hypothetical ^{14}C and ^{36}Cl LARS presented in Tables 5 and 6 shows even more its importance, as the differences on the inferred efficiencies ($\Delta\varepsilon$) would be much larger than those shown in Tables 3 and 4

However differences on efficiencies due to variability seems to be as significant as due to uniformity itself, as the attributed efficiencies might vary from any value found between the marginal and central distributions, which systematically underestimates and overestimates the instrument efficiency. It can therefore be stated that uniformity is not a sufficient parameter for characterizing large area reference sources. The variation in the efficiency values that would be attributed to instrument suggests that source mapping and evaluation on the application of correction factors are necessary steps in calibration procedures of surface contamination radiation monitors.

3. Conclusions

The evaluation of the correction factors for LARS with uniformity values above 90% but different variabilities, shows that instrument efficiency estimates may vary up to 14% of the uncorrected value, which is almost as high as differences observed for the ^{14}C LARS that presents a uniformity value of 50%, far below the minimum 90% value. It shows the importance of the LARS variability in instrument calibration procedures and the application of correction factors regardless of the uniformity value of the LARS used.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Iremar Alves da Silva: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Paulo de T.D. Siqueira:**

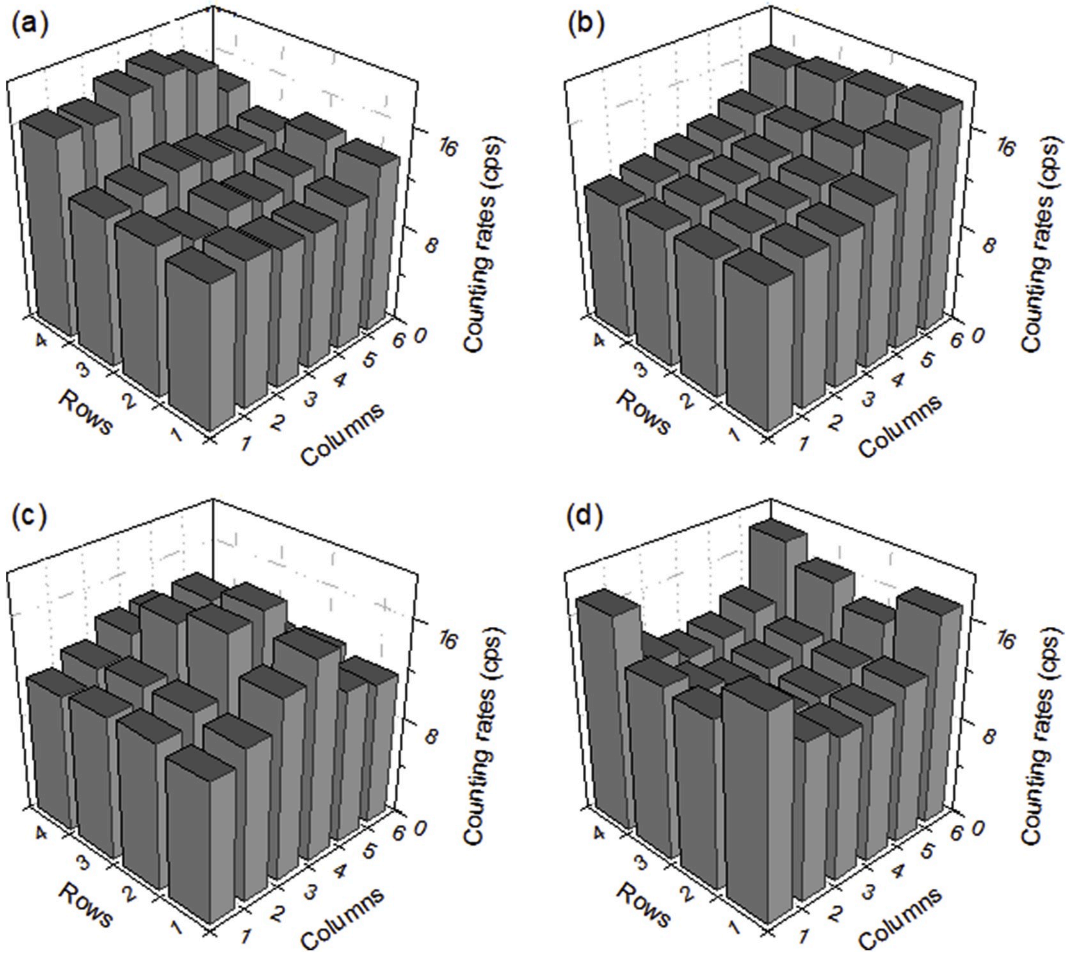

Fig. 5. ^{36}Cl Surface Source Distributions: (a) Original distribution; (b) Slope distribution; (c) Central distribution and (d) Marginal distribution.

Table 5
^{14}C Sources variability study.

$\varepsilon_{corrected} = 23.8\%$

Distribution	CF	ε (%)	Δε (%)
Original	1.179	20.2	−15.2
Slope	1.081	22.0	−7.5
Central	0.520	45.8	92.3
Marginal	2.118	11.2	−52.8

Table 6
^{36}Cl Sources variability study.

$\varepsilon_{corrected} = 52.3\%$

Distribution	CF	ε (%)	Δε (%)
Original	1.074	48.7	−6.9
Slope	1.063	49.2	−5.9
Central	0.780	67.1	28.2
Marginal	1.178	44.4	−15.1

Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Eduardo do Nascimento:** Software, Formal analysis, Writing - original draft, Writing - review & editing. **Hélio Yoriyaz:** Writing - review & editing, Visualization. **Gian-Maria A.A. Sordi:** Writing - review & editing. **Maria da Penha A. Potiens:** Resources, Writing - review & editing.

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