Analysis of the influence of the calibration support for measuring Kerma in air and determination of correction factors due to the influence of radiation scattered by the calibration setup and due to the geometry of the $^{192}$Ir sources.

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Abstract

The study was aimed at analyzing the influence of a fixation setup to measure air kerma rate. The calibration system was developed experimentally at the Radiological Sciences Laboratory of the State University of Rio de Janeiro (LCR-UERJ). The aim was to determine correction factors due to scattered radiation and also determine correction factors due to the geometry of the sources measured with the Well-type chamber. To this end, the parameters evaluated were: comparison of the experimental result with the computational result of the multiple distance method (technique established by the University of Wisconsin); Kerma determination in the reference air using thimble-type chambers; analysis of the source spectrum with and without encapsulation; and determining the source position for the maximum ionization region for the Sourcecheck 4PI chamber (Well Type). The air kerma intensity per activity in this work was and for chambers TN 30001 and NE 2571, respectively, with an expanded uncertainty of 0.932% and 0.919% in that order, for a coverage factor (k = 2). The correction factors due to the influence of the calibration set-up for measurements at 1 cm and 10 cm from the source were 0.135 and 0.122, respectively. The geometric correction factor of the sources was 0.700% with an expanded uncertainty for a coverage factor (k = 2). This value has a difference of approximately 0.220% compared to Shipley DR's experimental values.

Keywords: Kerma rate; Expanded Uncertainty; Monte Carlo Code; correction factors.
1.- INTRODUCTION

In order to maintain the metrological traceability of the dosimetric system using $^{192}$Ir High Dose Rate (HDR) sources, several published works have sought to show a methodology for calibrating sources (Di Prinzio, et al., 2009) (Goetsch, et al., 1991) (Brian E, et al., 2011) that allow them to be dosed in such a way as to minimize the uncertainties of the prescribed dose. Determining the kerma rate in the reference air is one of the relevant results in the metrological analysis of a calibration system, since it is a variable belonging to the equation for calculating the calibration coefficient of well-type ionization chambers.

The intensity of the sources in terms of the reference air Kerma rate (RAKR), recommended by the British Committee on Radiation Units and Measurements for use in high dose rate (HDR) brachytherapy (in prostate cancer treatments, in the lung, breast, pancreas, head and neck regions, among others), is a parameter that makes up a group of correction coefficients for calculating the calibration coefficient ($N_K$) of Well-Type Chambers from different manufacturers. In recent years, using Monte Carlo transport codes (MCNP, GEANT, EGS, PENELOPE) and experimentally, the calculation of Kerma and correction factors for obtaining this quantity indirectly using well chambers have been scattered throughout various articles (journals and conference proceedings), so it was considered useful to determine it computationally for the calibration setup developed at the Radiological Sciences Laboratory of the State University of Rio de Janeiro (LCR/UERJ), since it provides calibration services throughout Brazil.

The aim of this study was to analyze the influence of the fixation setup used to obtain the physical quantity Rate of kerma in air in a calibration system developed experimentally at the Radiological Sciences Laboratory of the State University of Rio de Janeiro (LCR-UERJ), determining correction factors due to scattered radiation and also determining correction factors due to the geometry of the sources measured with the Well-type chamber.
2. MATERIALS AND METHODS

The simulations were conducted assuming dry air conditions between the source and the detector, and the calibration setup was created computationally using geometric data from the sources and chambers, and built using the Monte Carlo Method (MMC) tools in the Penelope code.

2.1. Thimble-type chamber geometry model TN 30001 E NE 2571 Farmer

The chambers were built using the Monte Carlo Method (MMC) with computer codes (Salvat, et al., 2008) to simulate the proposed problem. The geometric characteristics of the TN 30001- NE 2571 thimble-type ionization chambers, such as the type of electrode, sensitive volume, sensitive volume wall material and equilibrium layer, are shown in Table 1 and Table 2.

Table 1.- Characteristics of the volume of interest of the Farmer TN 30001 type ionization chamber

<table>
<thead>
<tr>
<th>Physical structure of the Farmer PTW chamber</th>
<th>Material</th>
<th>Diameter (mm)</th>
<th>TN 30001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode</td>
<td>Aluminum</td>
<td>1.10</td>
<td>21.20</td>
</tr>
<tr>
<td>Graphite wall</td>
<td>PMM + Graphite</td>
<td>6.30</td>
<td>0.335 mm PMMA + 0.09 mm Graphite = 0.425mm</td>
</tr>
<tr>
<td>Electronic balancing cap</td>
<td>PMMA</td>
<td>16.40</td>
<td>4.55</td>
</tr>
<tr>
<td>Sensitive volume</td>
<td>Air</td>
<td>600.00</td>
<td>23.00</td>
</tr>
</tbody>
</table>
Table 2.- Characteristics of the volume of interest of the Farmer NE 2571 type ionization chamber

<table>
<thead>
<tr>
<th>Physical structure of the Farmer NE chamber</th>
<th>NE 2571</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrode</strong></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Aluminum</td>
</tr>
<tr>
<td><strong>Graphite wall</strong></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>99.99% Graphite</td>
</tr>
<tr>
<td><strong>Electronic balancing cap</strong></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Delrin $CH_2O$</td>
</tr>
<tr>
<td><strong>Sensitive volume</strong></td>
<td>Material</td>
</tr>
<tr>
<td></td>
<td>Air</td>
</tr>
</tbody>
</table>

The chambers in the two sets have identical external appearances, differing only in their intrinsic characteristics, such as wall thickness, thickness and electrical conductivity of the central electrode, sensitive volume, etc. Some of these may interfere with the result, such as the influence of the axis of symmetry on the exposure geometry.

### 2.2. Geometry of the radiation source

The Nucletron microSelectron-v2 (mSv2) source, manufactured by Nucletron Engineering BV - Netherlands, was built from the measurements provided, generating a 3.6 mm long and 0.65 mm diameter cylinder of metallic iridium with a uniform distribution of $^{192}$Ir and encapsulated in a 0.9 mm outer diameter AISI 316L stainless steel capsule, welded to a 0.7 mm thick and 1500 mm long steel cable. The GammaMedplus (GMp) source, manufactured by Varian - USA, was made by generating a cylinder 3.5 mm long and 0.70 mm in diameter of iridium and its encapsulation is 0.9 mm in external diameter, welded to a steel cable 0.61 mm thick and 1250 mm long.

Using the code, the following materials were built: source; encapsulation material; cables and so on. These materials are predetermined in the code, but you can create materials by entering the data in the material.exe executable.
The spectrum used in the simulation with the source corresponds to the model already known and used as a reference in several published articles that work with this source model for computer simulation (Smith BR, et al., 2017), (Naeem, et al., 2016). This spectrum is for a pure $^{192}$Ir "Bere" source where it was used for the simulation of this work in the construction of the source geometry with the encapsulation. The energy distribution of the initial photons from an ablated $^{192}$Ir source was reproduced according to data obtained by Borg and Rogers (Borg, et al., 1999).

$^{192}$Ir is produced when the chemical element absorbs a neutron inducing it to decay by $\beta^-$ (95.13%) transition to various excited states of $^{192}$Pt and by electronic capture to the excited levels of $^{192}$Os, emitting gamma rays at various energies. With a half-life of 73.827 days (Podgorsak, et al., 1992). On average, one decay provides 1 electron and 2.363 photons, so the number of photons emitted per second is directly proportional to the "A" activity and the number of photons provided in this decay.

Information on the energy distribution of the open source was obtained from Borg and Roger (Borg, et al., 1999). The energy distribution of the $^{192}$Ir radionuclide is shown in Figure 1, which shows the spectrum without and with source encapsulation. In the case where sources are sealed, the energy distribution spectrum varies due to the absorption of low energy beams by the material of the capsule containing the source, showing a damping of the aspect.

2.3.- Geometry of the experimental calibration setup reproduced in the computer simulation.

In the calibration system used in the LCR, a calibration setup was developed consisting of seven different positions between the source and the chamber, where the energy deposited in a volume of air can be measured. In this set-up, the position of the ionization chamber was varied and the source was kept fixed at a distance of 17 cm from a reference point for the source/chamber fixing bracket. This ensured the reproducibility of the measurements of the seven distances.
This system made it possible to vary the position of the ionization chamber in 7 different positions ranging from distances of approximately 10 cm to 40 cm, respectively keeping the position of the source always longitudinal to the chamber and with the geometric center of both the chamber and the source always in the same reference position, that is, varying only the distance keeping the central position of the air volume where the interactions take place in the same central position as the source, the simulated geometry was positioned in the geometric center of the Penelope coordinate system.

The source fixing system is made of 99.98% aluminum and the fixing material for the supports is acrylic, as are the rods for fixing the source and the camera, respectively. It was noted that the aluminum bracket had "holes" in the structure. The aim of this is to reduce the amount of material in the support for the source and the camera where possible interactions can occur, thus reducing the effects of scattered radiation on the site and on the supports, as well as the effective measuring point of the chamber, which contributes to the reading of photons in the sensitive volume of interest.

The materials were generated using the (.mat) file and the geometries were defined in the (.geo) file. All the physics used in the simulation was determined in the input file (.in). A simulation time in the order of $10^9$ stories was determined, with a simulation time in the same order of magnitude.

2.4.- Well-type chamber geometry

As Penelope works with previously defined quadratic surfaces, a geometry was constructed from the inside out where the inner cylinder contains the air material. The characteristics of the materials such as density, chemical composition, energy, among others, were studied beforehand and the materials were generated using the material.exe program from the Penelope package. Figure 5 shows the model built by computer simulation of a Well Type Ltd. chamber no. 5637. Details of physical and electronic properties are not given in this work for confidentiality reasons.
2.5.- Calculation of the Kerma Rate in the Reference Air

Considering the energy deposited in a volume of air at a reference distance "d" from the center of the source, we sought to determine the value of the Kerma rate in the air. According to Borg & Roger (Borg, et al., 1999) the fluence at a point P is numerically equal to the expected value of the sum of the lengths of the particle tracks (assumed to be straight) that occur in an infinitesimal volume $dV$ at a point "P". Kerma in air is related to photon fluence using equation (1):

$$\dot{K}(d)_{\text{air}} = 1.602 \times 10^{-19} \int_{h.v_{\text{Min}}}^{h.v_{\text{Max}}} \left( \frac{dN(h.v)}{da} \right) \left( \frac{\mu_{\text{en}}(h.v)}{\rho} \right)_{E,Z} \bar{E}_i(h.v) \times d(h.v)$$

(1)

Where $\Psi(E) = \frac{dN(h.v)}{dN(h.v)} \left[ \frac{\text{Energy}}{\text{Area}} \right]$ is the fluency in energy and $\left( \frac{\mu_{\text{en}}(E)}{\rho} \right)_{E,Z} \left[ \frac{\text{cm}^2}{\text{g}} \right]$ mass absorption coefficient. the mass energy absorption coefficient for dry air was taken from the NIST (NIST, 2023).

After some mathematical manipulations, using Borg’s work as a reference, we have the expression described in equation (2).

$$\frac{k_R}{A} = \dot{K}(d)_{\text{air}} \times d^2(2.363)$$

(2)

Where "d" is the distance to the central axis of the chamber's air volume, in this case the cylindrical air volume of interest. The recommended unit for the Kerma quantity in the reference air,$k_R$, is $\text{Gy h}^{-1}$ to 1 m. According to Borg (Borg, et al., 1999) the previous expression becomes:

$$\frac{k_R}{A} = 3.6 \times 10^9 \times \dot{K}(d)_{\text{air}} \times d^2 \times (2.363 \pm 0.3\%)$$

(3)

Where the value of $k_R$ can be determined by knowing the activity of the source (in Bq) at the time the measurement is made with the appropriate corrections, since the activity of the source depends on the number of disintegrations per unit time. The correction factors in equation (3) guarantee the order of magnitude in determining $k_R$. 
2.6.- Calculation of the correction factor due to Source Geometry \( (k_{sg}) \)

The geometric factor, due to the physical characteristics of the sources (dimensions, shapes, determined), can be determined using equation (4). Since the physical characteristics of the sources can vary from manufacturer to manufacturer, these corrections must be taken into account when measuring the kerma in the reference air measured in clinics using well chambers.

\[
k_{sg} = \frac{\text{Energy}_{MS}}{\text{Energy}_{GM}}
\]

(4)

Where \( \text{Energy}_{MS} \) is the energy deposited in the sensitive volume of the well chamber obtained in the simulation with the source MicroSelectron; \( \text{Energy}_{GM} \) is the energy deposited in the sensitive volume of the well chamber obtained in the simulation with the source GammaMed e \( k_{sg} \) is defined as the value of the geometric factor.

3.- RESULTS

The results obtained in this work are presented below, in order to verify and analyze the methodology for obtaining the Kerma Rate in the Reference air, and the LCR calibration system. Comparisons were made between the experimental results and those obtained by computer simulation. A comparison was made between experimental and computer modeling results.
3.1.- Source spectrum change after encapsulation

Analysis of the source spectrum after encapsulation (Figure 1) shows a change in the source spectrum, calculated by computer simulation considering the vacuum medium. To simulate the spectrum, an air detector was placed 1 cm from the source so that all the energy released by the source could be collected in the simulation. The simulation was carried out at a point where the chamber and the source were very close to guarantee this deposition of energy in the sensitive volume of interest. (Ferreira, et al., 1999).
Figure 1.- Photon spectra bere (pure) (a) and a (b) with stainless steel encapsulation (results adapted) (Borg, et al., 1999)).

Figure 1 (b) shows that the encapsulation modifies the spectrum of the $^{192}$Ir source, mainly affecting the low-energy part of the photon spectrum. In acquiring this data, we considered a source immersed in an air detector where it occupies the center so that the energy distribution is as isotropic as possible. This modification was observed in the range between 0.1 and 0.5 cm. This damping in this range generates a count of higher energy photons interacting with the sensitive volume region of the detector, so only the highest energy photons are counted.

3.2.- Verification of the multiple distance method in the LCR calibration setup.

The construction of the calibration setup by computer simulation is shown in Figure 2, which shows the source and the chamber positioned on the mounting bracket.
Figure 2. - Calibration setup developed at the LCR/ UERJ: In (a) there is: in red the Al support, in dark blue the PMMA plate and in light blue the "holes" made to reduce the amount of material and reduce scattered radiation due to interaction with the support and in yellow, the chamber stop positions, which have been numbered from 1 to 7. In (b) there are: in light blue the PMMA supports, in pink the chamber fixing support, in red the chamber base, in light blue the buildup cover and in green the air volume.

The validation of the multiple distance method was carried out by normalizing the measurement to the value of the maximum energy deposited in the chamber, that is, to the energy stored in the chamber's sensitive volume at the 10.742 cm position, since in the
calibration system this is the closest position between the chamber and the source. This was done to make it easier to compare two measurements taken in different units. The experimental measurement was taken in nano Coulomb (nC) and the computer simulation in eV/particle. Figure 3 shows the profile of the curve obtained for this work in comparison with the normalized experimental curve. The curves show a significant correlation, since the value of the Pearson coefficient for curves referring to the values obtained in the simulation is $R^2 = 1$.

Figure 3. - Experimental measurement versus simulated normalized to the maximum reading value showing the behavior of the primary radiation from the source with distance, verifying that the inverse square of the distance law is obeyed for the seven source-camera distances obtained with the TN 30001 camera in the positioning system in the comparison of experimental versus computational measurement.

The measurements related to the multiple distance method, using the Penelope Code, show a mathematical profile very close to the distribution of the data obtained in Di Prinzio's work. The sample correlation coefficient was $R^2 = 1$ for the data obtained experimentally, as well as for the data obtained by computer simulation. The comparison shows that both have a negative non-linear correlation, since as the distance increases, there is less energy
deposition in the sensitive volume of interest due to the infinitesimal volume of the chamber.

3.3. Position of the source in the well chamber for maximum reading of the energy deposited in the sensitive volume of air

In order to use the well chamber, we need to make sure that all the energy released by the photons is being collected. We therefore determined the maximum reading position of that chamber for the (GMP) and (mSv2) source models. To do this, the Sourcecheck 4PI well chamber was developed computationally, as shown in Figure 4.
Figure 4. - (a) 2D Well Type chamber obtained in Penelope (b) 3 D view of the chamber.

The reading deviation from the maximum position for the (mSv2) source at breakpoints 5.5 and 6.5 in relation to the central position (maximum point of the function) was 0.150% and 0.176% respectively. Using the (GMp) source, the well chamber showed values of 0.199% and 0.724% at breakpoints 6.0 and 7.0, respectively.

Figure 5. - Position of maximum well chamber reading: Sensitivity curve of the well chamber response as a function of distance from the source along the axial axis, using the (mSv2) and (GMp) sources.
It was found for this chamber that the point of maximum ionization is not exactly in the same position when measurements are made with sources of different geometries. Since the maximum energy deposition value had a maximum variation of approximately 0.724% for measurements with the (GMp) source.

3.4.- Kerma Rate in Reference Air by Activity.

The estimated air kerma intensity per activity in this study was $1.725 \times 10^{-03}$ Gy. Bq$^{-1}$ for NE chambers and $1.710 \times 10^{-03}$ Gy. Bq$^{-1}$ for TN 30001 and NE 2571 chambers, with an uncertainty of 0.932% and 0.919% respectively for a coverage factor of k=2 as described in Table 3 - According to Borg J, Rogers (Borg, et al., 1999), the Bremsstrahlung causes the Kerma in the air to increase in intensity by 0.2%.

<table>
<thead>
<tr>
<th>Farmer-type Chambers</th>
<th>$K_R/A$</th>
<th>Expanded Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NE 2571</td>
<td>$1.725 \times 10^{-03}$</td>
<td>0.932%</td>
</tr>
<tr>
<td>TN 30001</td>
<td>$1.710 \times 10^{-03}$</td>
<td>0.919%</td>
</tr>
</tbody>
</table>

Table 4 shows the estimate for Kerma in the reference air considering the measurement made with a 12.3 Ci activity source, under the same conditions as the experimental measurement. These values together with the uncertainty calculated in the simulation were 21.660 mGy. h$^{-1}$ using TN 30001 chambers and 21.220 mGy. h$^{-1}$ for the NE 2571 chamber with coverage factor k = 2 at 1 m from the source for an activity of 12.3Ci (value of the source activity from the experimental work).
Table 4.- Comparison of Kerma Rate values in Reference Air at 1 m for an activity of 12.3 Ci. Column (A) measured by Prinzio; column (B) measured in this study.

<table>
<thead>
<tr>
<th>Farmer-type Chambers</th>
<th>$K_R (mGy h^{-1})$ a 1 m</th>
<th>(A/B)</th>
<th>Relative deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN 30001</td>
<td>21.660</td>
<td>21.033</td>
<td>1.030</td>
</tr>
<tr>
<td>NE 2571</td>
<td>21.220</td>
<td>21.221</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Measurements with the TN 30001 chamber showed a relative deviation of 2.890% compared to the experimental measurements, indicating the need to readjust the geometry model obtained by computer simulation or even correct the computationally described setup. For the NE 2571 chamber, this relative deviation was 0.005%, which shows that the system developed computationally using this measurement configuration is consistent with the experimental measurements. In this sense, the NE 2571 chambers proved to be more stable.

3.5.- Fluency change due to the presence of the measurement setup

In order to verify the contribution of scattered radiation due to the aluminum support, the influence of the positioning system was studied. In this configuration, values were considered with and without the aluminum support with the camera 1 cm from the source, curves (a) and (b), and values in the same configuration with the camera approximately 10 cm from the source, curves (c) and (d).

Figure 6 shows that in the 0.0 to 0.3 Mev range, for lower energies, the fluence spectrum showed changes for curves (a) and (b), with a peak in the fluence spectrum due to the placement of the calibration support. This is due to the interaction of these scattered photons with the chamber's sensitive volume region, which is accounted for and generates this change.
in the spectrum, which can contribute to the uncertainty of the physical quantity measured. The percentage contribution was 13.46%.

Figure 6. - Fluence spectrum with and without measurement setup at 1cm from the source.

For a position of approximately 10 cm, Figure 7 shows that in the 0.0 to 0.3 Mev range, the spectrum showed greater distortion in this range. This may have been due to the influence of changing the position of the camera, increasing the interaction region of the fixation support, and thus the greater contribution of scattered radiation, which may have caused this behavior. The percentage contribution in this position was approximately 12.24%.
Table 5 shows the correction value due to the influence of the calibration setup. By making vacancies along the Al support so that there is a smaller amount of material, the probability of interaction between these photons and possible scattering that could contribute to the reading of the cameras can be reduced. However, it is necessary to make corrections to the measurements since the camera needs to be fixed in front of the source in order to guarantee reproducibility in the measurement.

Table 5. - Correction factors due to the influence of the chamber mounting bracket and the source

<table>
<thead>
<tr>
<th>chamber position in front of the source</th>
<th>1 cm</th>
<th>10 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution percentage</td>
<td>13.459%</td>
<td>12.244%</td>
</tr>
<tr>
<td>Correction Factor</td>
<td>0.135</td>
<td>0.122</td>
</tr>
</tbody>
</table>

Figure 7. - Fluence spectrum with and without measurement setup at 10 cm from the source
3.6.- Correction factor due to source geometry \( (k_{sg}) \)

Using the 4PI source check camera (Well Type), the geometric correction factor of the sources was analyzed and \( k_{sg} = 1.005 \) was obtained. This value has a difference of 0.220% compared to the experimental values of Shipley DR (Shipley, et al., 2015), as shown in Table 6.

Table 6. - Geometric factor for correcting the \( K_R \) value when measuring with the Well chamber

<table>
<thead>
<tr>
<th>Relationship between sources</th>
<th>Geometric Factor ( (k_{sg}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucletron microSelectron-v2/ Isodose Control Flexisource</td>
<td>1.004 ± 0.004</td>
</tr>
<tr>
<td>GammaMed Plus / Isodose Control Flexisource</td>
<td>1.001 ± 0.004</td>
</tr>
<tr>
<td>Nucletron microSelectron-v2/ GammaMed Plus/</td>
<td>1.003 ± 0.004</td>
</tr>
<tr>
<td>Nucletron microSelectron-v2/ GammaMed Plus (This work)</td>
<td>1.005 ± 0.007</td>
</tr>
</tbody>
</table>

The precise response of the Sourcecheck 4pi chamber is influenced by air density, a variable that is subject to fluctuations due to environmental factors such as temperature, pressure and humidity (Torres del Río, et al., 2018). Therefore, in order to guarantee the reliability and accuracy of the measurements, it is essential to apply a geometric correction factor. This factor adjusts the measurements to the specific conditions under which the measurements are taken, taking into account the effects of variations in air density.

4.- DISCUSSION

Looking at Figure 1 (b), it becomes clear that this encapsulation not only alters the spectrum, but also has a particularly significant effect on the low-energy portion of the photon spectrum. To obtain this data, it is important to note that the source was positioned centrally, thus allowing the energy distribution to be as isotropic as possible. This approach ensures that the
analysis of the results is based on controlled and comparable conditions, in order to obtain accurate conclusions about the behavior of the $^{192}$Ir source.

The phenomenon observed, in which the modification of the spectrum is most evident in the 0.1 to 0.5 cm range. Within this range, damping occurs, resulting in a higher count of high-energy photons interacting with the detector's sensitive region. This suggests that the energy that is damped in this interval ends up being redirected towards higher energy photons, which are more likely to interact with the detector's sensitive region.

The direct consequence of this is that only the highest energy photons are recorded. This can have important implications for the interpretation of data obtained from the $^{192}$Ir source, especially in applications that depend on the detection of photons in different energy ranges.

The measurements made with the multiple distance method, using the Penelope Code, exhibit a mathematical profile that is highly convergent with the distribution of data previously obtained in Di Prinzio's work. The sample correlation coefficient of $R^2 = 1$ for both experimental and simulation data sets is a strong indication of the accuracy of the method and the agreement between the results obtained by different approaches.

The negative non-linear correlation between distance and energy deposition in the sensitive volume of the chamber is a relevant observation, since this trend is explained by the small size of the chamber volume. As the distance between the source and detector increases, the energy deposition in the sensitive volume decreases considerably.

The reading deviation from the maximum position, shown in Figure 5, for the (mSv2) source was evaluated at different breakpoints, 5.5 and 6.5, in relation to the central position of the function. The results show deviations of 0.150% and 0.176% respectively, demonstrating a slight variation in the measurements. On the other hand, when using the (GMp) source, the well chamber showed more pronounced reading deviations, with values of 0.199% and 0.724% at breakpoints 6.0 and 7.0, respective.

The point of maximum ionization does not coincide in exactly the same positions when measurements are made with sources of different geometries. This phenomenon can be seen in the discrepancy in the variations of the maximum energy deposition values. The maximum
variation of around 0.724% in measurements with the (GMp) source indicates a greater influence of the source geometry on the position of maximum ionization in the well chamber.

Kerma estimates in the reference air, considering an activity source of 12.3 Ci under the same experimental conditions. The calculated values, together with the uncertainties derived from the simulation, were 21.660 mGy. h⁻¹ for the TN 30001 chambers and 21.220 mGy. h⁻¹ for the NE 2571 chamber, both with a coverage factor of $k = 2$ at 1 meter from the source. These values are compared with the experimental measurements taken.

With regard to the differences between the computational estimates and the experimental measurements, the TN 30001 chamber showed a relative deviation of 2.890%. This deviation suggests the need to readjust the geometry model used in the simulation or consider corrections to the computationally described setup. In contrast, the NE 2571 chamber exhibited a relative deviation of only 0.005%, indicating that the computationally developed system with this measurement setup is congruent with the experimental measurements.

With regard to the change in fluence due to the presence of the measurement setup, Figure 9 shows that in the 0.0 to 0.3 MeV range, for lower energies, curves (a) and (b) showed a peak in the fluence spectrum. This peak is attributed to the interaction of the scattered photons with the chamber's sensitive volume region. These scattered photons are accounted for and result in the observed change in the spectrum, contributing to the measurement uncertainty. The percentage contribution of this change was estimated at 13.46%.

Furthermore, when looking at Figure 10 for a position of approximately 10 cm, the spectrum in the 0.0 to 0.3 MeV range showed greater distortion. This is explained by the change in the position of the camera, which increases the region of interaction with the mounting bracket. With a greater contribution from scattered radiation, it is possible that this change in the behavior of the spectrum occurred. The percentage contribution in this position was calculated to be around 12.24%.

The geometric correction factor for sources using the Sourcecheck 4pi camera, which is a well-type camera. This correction factor is essential to ensure that the measurements taken with the camera are correctly adjusted to the characteristics of the detection geometry.
The value of the geometric correction factor obtained, \( k_{sg} = 1.005 \), is compared with previous experimental values reported by Shipley et al. in 2015. The difference between the calculated value and the experimental values is mentioned as being 0.220%.

Comparing the results obtained with the experimental values from Shipley et al. is an important way of validating the method used to determine the geometric correction factor. A difference of 0.220% is not insignificant and suggests that there may be additional factors or details in the geometry that are affecting the measurements and leading to this discrepancy.

5.- CONCLUSIONS

In summary, we determined the correction factors due to the influence of the aluminum fixing setup, which contributed 13.459% to the measurement at 1 cm from the source and 12.244% at the 10 cm position. We were also able to obtain the value of the correction factor due to the geometry of the source, which has an expanded uncertainty of 0.700% for a coverage factor (\( k = 2 \)). This value is approximately 0.220% different from the experimental values compared to other authors. It was also observed that the physical parameters, such as the inverse square law of distance, the geometric profile of the source with depth, among others, could be reproduced. It was possible to determine correction factors to reduce uncertainties in the measurement of Kerma in air. In this sense, this work contributes to the analysis of parameters that would sometimes be complex to determine experimentally. These results will help to reduce the uncertainties in the calculation of air kerma, which will consequently reduce the uncertainties in the final dose delivered to the patient in brachytherapy treatments in clinics. In short, the article has contributed to the literature by providing a comprehensive and insightful analysis of kerma determination, stimulating constructive debate and encouraging researchers to explore new avenues to advance knowledge on this complex and relevant subject.
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