Correlation and uncertainties evaluation in backscattering of entrance surface air kerma measurements

GJ Teixeira\textsuperscript{1,2,4}, CHS Sousa\textsuperscript{1}, JGP Peixoto\textsuperscript{1,3}

\textsuperscript{1}Instituto de Radioproteção e Dosimetria (IRD/CNEN); \\
\textsuperscript{2}Curso Superior de Tecnologia em Radiologia (CSTRAD/UNESA); \\
\textsuperscript{3}Laboratório de Ciências Radiológicas (LCR/UERJ); \\
\textsuperscript{4}Faculdade de Ciências Médicas (FCM/UERJ)

E-mail: gt@ird.gov.br

Abstract: The air kerma measurement is important to verify the applied doses in radiodiagnostic. The literature determines some methods to measure the entrance surface air kerma or entrance surface dose but some of these methods may increase the measurement with the backscattering. Was done setups os measurements to do correlations between them. The expanded uncertainty exceeded 5\% for measurements with backscattering, reaching 8.36\%, while in situations where the backscattering was avoided, the uncertainty was 3.43\%.

1. Introduction

Entrance Surface Air Kerma measurements (ESAK) are relevant for the verification of the applied doses in radiodiagnostic. These measurements are performed at the corresponding point to the flat surface of a specified object. The object may be any region of a patient or a simulator and the results associated with a backscatter factor [1].

Thermoluminescent dosimeters (TLD) are the most recommended for these measurements because they can be positioned in the patients themselves and the readings do not require corrections [2]. Despite the recommendations, there is the problem of the dynamics of the use of the TLD, being complex because professionals in this field do not always have at their disposal a dosimetry laboratory, which makes this method very expensive. The resolution of this problem can be the use of the ionizing chamber (IC) for the measurements.

The IC should be calibrated by accredited laboratories, making them traceable. This calibration is performed 1 meter from source [2; 3] in a collimated beam and compared to a standard reference chamber. It turns out that the available protocols for entrance surface dose and entrance surface air kerma measurements differ from the calibration method.

TRS 457 [2] recommends that ESAK measurements, when performed by ionization chambers, are obtained from the Incident Air Kerma (IAK) measurements and then corrected by the inverse square law. The IAK, according to the TRS, is obtained by positioning the IC between the simulator and the tube, significantly reducing the distance between the source and the detector (less than 1 meter), so the distance is different from the instrument calibration.

An ESD measurement methodology published by the National Agency for Sanitary Surveillance - Brazil (ANVISA) in the Equipment Safety and Performance Manual [4], recommends that the ionization chamber be placed on a support at a distance corresponding to the plane of the simulator or patient, or on the table. When correct adjustment of the distance between the Xray tube and the
detector is not feasible, it is recommended that the measurements be corrected by the inverse law of the square of the distance.

The position of the IC in the examination table may involve the production of backscattering from the interaction of the primary beam with the table itself and, depending on the distance and the radiographic technique employed, can determine if the radiology service is in a "compliance" situation or "Non-compliance" situation with radiation protection recommendations and standards. This effect was not described in any reference literature used in this study.

The measurement uncertainty is a parameter associated with the result of a measurement, which characterizes the dispersion of the values that can be reasonably attributed to the measurand [5]. The sources of uncertainty of a radiological measurement, due to the characteristics of the dosimetric systems and characteristics of X-ray equipment, can be diverse, such as pressure, temperature, energy dependency among others.

The objectives of this work involve the correlation between possible techniques for entrance surface air kerma measuring and the verification of the uncertainties involved in the process, covering the inverse square law for these measurements and relations between tube-detector-table distance of radiodiagnostic practices.

2. Materials and methods

2.1. Equipment and radiographic techniques

A radiodiagnostic equipment of 500 mA and voltage between 30 and 150 kV was used, with a high frequency generator. The lateral lumbar spine exam with radiographic technique used by the staff of the radiology service participating in the research was defined as the reference procedure. The time-to-current ratio was 100 mAs, being 200 mA and 0.5 s, with 80 kVp of voltage. The size of the field varied depending on the positioning of the IC due to the change of its sensitive area by the distance.

The radiographic technique was based on the reference man, with focus-film distance of 1 meter [6] and focus-object distance of 70 cm. Measurements were performed with a Radcal Dosimetric System, model 9015 with 6 cc cylindrical chamber, calibrated in terms of Air Kerma for a beam quality RQR 6 [2].

2.2. Setups

Measurements were made for 5 different experimental setups, varying the camera-source, table-source and table-chamber distances, with five readings for each setup and the average and standard deviations were calculated.

The setup to obtain the reference reading was performed with the X-ray tube in its maximum vertical displacement (Figure 1), establishing as 100 cm the tube-detector distance (detector at 30 cm from the table) avoiding backscatter (Setup 1 - S1).

![Figure 1. Setup for reference reading.](image)
The chamber was also positioned at 20 cm (Setup 2 - S2) and 10 cm (setup 3 - S3) of the table, keeping the tube within 1 meter of the detector to verify the influence of the backscattered radiation at those distances, that is, with the tube (Focal point) at 120 cm and 110 cm from the table. Another setup was mounted, so that the effective focal point of the chamber was positioned closer to the table (3 cm) (figure 2) with the tube at 100 cm from the chamber (setup 4 - S4).

**Figure 2.** Arrangement with the ionization chamber near 3 cm from the backscattering source.

Setup 5 (S5) consisted of positioning the chamber 30 cm from the table with the tube 70 cm from the chamber (figure 3), according to recommendations [2; 4]. Finally, the measurements obtained with S1 were corrected by the inverse square law to 70cm that we call here by T1.

**Figure 3.** Setup 5.

2.3. Backscattering factor

With the measurements of setup 4 an increase in dose was observed in relation to setups 1, 2 and 3, being defined by:

\[ BS = \left| L_d - L_p \right| \]  \hspace{1cm} (1)

where \( L_d \) is the average reading between S1, S2 and S3 and \( L_p \) is the average reading with the detector 3 cm from table top (S4) and the backscattering factor (BSF) defined as the ratio between the same average readings \( (L_d/L_p) \).

2.4. Correlations

Three correlations were made, one being between the results of setups 1 and 4, another between the results of setup 4 and the same results with the application of BSF (S4B). The third correlation was
performed between S5 and T1. The average and standard deviations [7] of the series of measurements for the correlation were determined by applying the Pearson momentum, according to equation

$$r_{xy} = \frac{\left( \frac{1}{n} \sum_{i=1}^{n} x_i y_i \right) - \left( \frac{1}{n} \sum_{i=1}^{n} x_i \right) \left( \frac{1}{n} \sum_{i=1}^{n} y_i \right)}{\sqrt{\left( \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right) \left( \frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2 \right)}}$$

(2)

where $x_i$ corresponds to the independent measurements related to each setup and $y_i$ corresponds to the independent measurements related to the other series of measurements that were correlated with $x_i$ [7].

Once the correlation between the input quantities was established, the combined variance of the input quantities $x_i$ and $y_i$ was determined, being these type A, according to equation 3,

$$S(x, y) = \left( \frac{1}{n(n-1)} \right) \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})$$

(3)

2.5. Uncertainties evaluation
To evaluate the uncertainties, the recommendations of the Guide to the Expression of Uncertainty of Measurement [7] were used, considering as uncertainty type A, the coefficient of variation of the series of measurements, through equation

$$\sigma(\%) = \frac{\sigma}{x} * 100$$

(4)

where $\sigma$ is the standard deviation and $x$ is the measurements average. The uncertainties type B are defined as the other contributions that were not obtained by statistical methods, that is, intrinsic data of the measurement system. This work considered only the energy dependence of the system, the resolution of the electrometer, the resolution of the distance measurement and the calibration factor of the ionizing chamber. The combined standard uncertainty ($u_c$), the expanded uncertainty ($U$) and the confidence interval ($k$) were calculated.

3. Results
Table 1 shows the results of the correlation of the measurements between the setups and their variances. It can be observed that all the setups presented a positive correlation, the correlation between S4 and their measurements with BSF (S4B) being an absolute correlation. Figure 4 shows the application of backscatter factor in S4 measurements.
Table 1. Correlation and variance between the setups

| Setup Combinations | Correlation ($r_{xy}$) | Variance ($X,Y$) |
|---------------------|------------------------|------------------|
| S1 and S4           | 0.1491                 | 0.1425           |
| S4 and S4B          | 1.0000                 | 0.0953           |
| S5 and T1           | 0.9385                 | 0.0506           |

Figure 4. Comparison of the values taken 3 cm from the table top with and without the BSF and the reference reading obtained with the chamber at 30 cm from the table top.

Table 2 shows the combined standard uncertainty ($u_c$), the expanded uncertainty ($U$), and the confidence level ($k$) for each measurement setup, and table 3 shows the correction of setup 1 by the inverse square law for 70 cm (T1), making evident the dose difference between the methods.

Table 2. Combined standard uncertainty ($u_c$), the expanded uncertainty ($U$) and the confidence interval ($k$) for each setup or method.

| Setup | $u_c$   | $U$     | $k$  |
|-------|---------|---------|------|
| S1    | 1.7117  | 3.4335  | 2    |
| S4    | 3.4444  | 8.3658  | 2.43 |
| S4B   | 3.4443  | 8.3654  | 2.43 |
| S5    | 1.7996  | 3.6065  | 2    |
| T1    | 1.8065  | 3.6216  | 2    |

Table 3. Comparison between the dose obtained at 100 cm corrected by the law inverse square law to 70 cm and the dose obtained at 70 cm by simulating the distance source-patient, the ratio and difference.

| Air Kerma (mGy)          |
|--------------------------|
| Average of reference reading taken at 100 cm | 4.797 |
| Average reference reading corrected to 70 cm | 9.790 |
| Average measurement at 70 cm | 10.238 |
| Difference                | 0.448 |

4. Discussion

The correlation between S5 and T1 shows that there is a strongly positive relationship between the methods, that is, the change in the measurement setup or the inverse law of the square of the distance are congruent. Observing Table 3, it can be concluded that the dose difference between the
measurements is high for radiodiagnostic. The non-positioning of the chamber at 100 cm implies a lack of traceability of the measurements, since the readings of the other distances could not be simply corrected by the law of the inverse of the square, this effect was also observed by Teixeira [8].

The backscattering factor (BSF) is presented and discussed in several articles [8] but always taking into account only the radiation scattered by the tissue or phantom equivalent to tissue, characterized as water or water phantom [2]. Clinical practice shows that the simulator is not used, leaving only the table as a scatter object. BSF is defined by

\[ BSF_X^{(W)} = \frac{X^{(W)} \left[ \frac{\mu_{tr}}{\rho_{w,air}} \right]^W}{X^{(free)} \left[ \frac{\mu_{tr}}{\rho_{w,air}} \right]^{(free)}} \]  

(5)

Where \( X^{(w)} \) is the Exposure on the water phantom surface, \( X^{(free)} \) is the Exposure at the same point of space in the absence of the simulator and \( \mu_{tr}/\rho \) is the proportion of mass transfer energy coefficients for water and air in the presence of disperser and free space.

This factor is important because of the increase in the actual measurement, but in this study only the backscattering produced by the interaction of ionizing radiation with the examination table was evaluated. It has been found that, due to the maximum displacement of the vertical tube of x-rays, it is necessary in some cases to bring the chamber closer to the table, which generates a significant backscattering.

The technique used in this work to determine the BSF was acceptable, since the correlation between S4 and S4B is absolute, since they are directly proportional. Figure 4 shows that the application of the BSF factor was efficient, but the expanded related uncertainty for these 2 setups exceeds 5% acceptable for radiodiagnostic measurements. The correlation between S1 and S4 shows a weak positive value, leading to the conclusion that the backscattering has a significant contribution to the dose and the variance in the measurements shows that the backscatter of the table is not homogeneous, resulting in a high coefficient of variation, 2.98%.

5. Conclusions

The calibration of the detectors is extremely important for any measurement of dosimetry and protection against radiation. The ionizing chambers, for their readings to be considered reliable, need to be calibrated in a standard reference laboratory for results to be traceable.

Current protocols recommend different ways of performing measurements of entrance surface air kerma and entrance surface dose, which makes the traceability of the absolute quantity air kerma confusing.

The adjustment of the values found with the detector 100 cm and corrected by the inverse square law differs significantly from the results of the measurements with the section of the detector in the plane of the patient or surface of the simulator.

The results obtained with the detector at the patient’s position for metrological purposes are not acceptable because ESAK or ESD reference values, according to standards and recommendations, are not subject to fluctuations but limits. It is recommended to do so, that measurements are taken at the same distance from the calibration to trace.
The approach of the ionization chamber to the examination table also generates a significant backscatter, which can be avoided by positioning the instrument away from the table, but is sometimes not feasible due to the maximum vertical displacement of the X-ray tube.

The ESAK or ESD verification with detector ionizing chambers is feasible and reliably replaces the TLD, eliminating even the uncertainty surrounding the thermoluminescent method. The feasibility and accuracy of the IC depend on the appropriate use. A setup of the same conditions as the standard reference laboratory is recommended. If it is not possible to remove the ionization chamber from the examination table, it is recommended to use an adequate backscatter factor.

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