

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

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**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 this methods may increase the measurement with the backscattering. Were done setups of 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%.

**Keywords:** Air kerma, Uncertainties, Backscattering.

### 1. INTRODUCTION

Entrance Surface Air Kerma measurements (ESAK) are relevant for the radiodiagnostic applied doses verification. 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 dynamics problem of the TLD use, being complex because professionals in this field do not always have at their disposal a dosimetry laboratory, which makes this method very expensive. This problem resolution could use the ionizing chamber (IC) for the measurements.

The IC should be calibrated by accredited laboratories, making them traceable. This

calibration is compared to a standard reference chamber, one meter from source [2; 3] in a collimated beam. 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 one 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 IC be placed on a support at a distance corresponding to the simulator or patient plane or

on the table. When correct adjustment of the distance between the X-ray 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 IC position in the examination table may involve the production of backscattering from the primary beam interaction with the table and also depending on the technique employed distance and the radiographic, 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 uncertainty is a parameter associated with the measurement result, which characterizes the values dispersion that can be reasonably attributed to the measurand [5]. The uncertainty sources of a radiological measurement, due to the characteristics of the dosimetric systems and X-ray equipment, can be diverse, such as pressure, temperature, energy dependency among others.

The objectives is involve the correlation between possible techniques for ESAK and its uncertainties 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. The

field size 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 one meter focus-film distance [6] and 0,70 meters focus-object distance. 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 five 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, establishing as 1 meter the tube-detector distance (0,30 m detector from the table) avoiding backscatter (Setup 1 - S1).

The chamber was also positioned at 20 cm (Setup 2 - S2) and 10 cm (setup 3 - S3) of the table, keeping the tube within one 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 chamber effective focal point was positioned 0,03 meters table closer with the tube at one meter from the chamber (setup 4 - S4).

Setup 5 (S5) consisted 0,3 meter chamber positioning from the table with the tube 0,70 meter from the chamber, figure 1, according to recommendations [2; 4]. Finally, the measurements obtained with S1 were corrected by the inverse square law to 0,70 meter, call T1.

### ***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:

$$BS = [L_d - L_p] \quad (1)$$

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

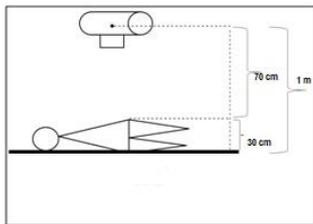


Figure 1 – Setup 5.

## 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 measurements series for the correlation were determined by applying the Pearson momentum, according to equation

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

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

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

$$S(\bar{x}, \bar{y}) = \left( \frac{1}{n(n-1)} \right) \sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y}) \quad (3)$$

## 2.5. Uncertainties evaluation

To evaluate the uncertainties [7] were considering as uncertainty type A, the coefficient of variation of the series of measurements, through equation

$$\sigma(\%) = \frac{\sigma}{\bar{x}} * 100 \quad (4)$$

where  $\sigma$  is standard deviation and  $\bar{x}$  is 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. Now considered only the system energy dependence, electrometer resolution, distance measurement resolution and IC calibration factor. The combined standard uncertainty (uc), the expanded uncertainty (U) and the confidence interval (k) were calculated.

## 3. RESULTS

Table 1 shows the measurements correlation results between setups and 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 2 shows the application of backscatter factor in S4 measurements.

**Table 1.** Setups Correlation and variance

Setup combinations	Correlation ( $r_{xy}$ )	Variance ( $x, y$ )
S1 e S4	0,1491	0,1425
S4 e S4B	1,0000	0,0953
S5 e T1	0,9385	0,0506

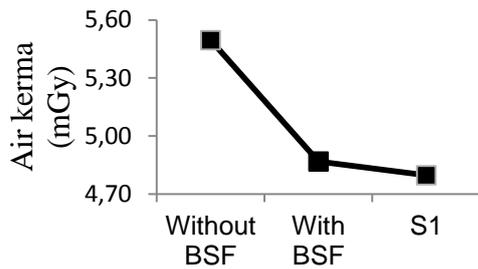


Figure 2 – Comparison values taken 0,03 m from the table top with and without the BSF and the reference reading obtained with the chamber at 0,30 m from the table top.

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 0,70 m (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 dose obtained at one meter corrected by the law inverse square law and the dose obtained at by simulating the distance source-patient 0,70 m.

Air Kerma (mGy)	
reference average (1 m)	4.797
Reference Average (0,70 m)	9.790
Average measurement (0,70 m)	10.238
Difference	0.448

#### 4. DISCUSSION

The correlation between S5 and T1 shows that there is a strongly positive, 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 one meter implies a lack of measurements traceability, since the readings of the other distances could not be simply corrected by the law of the inverse of the square [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

$$BSF_x^{(w)} = \frac{X^{(w)} \left[ \frac{\mu_{tr}}{\rho} \right]_{w,air}^{(w)}}{X^{(free)} \left[ \frac{\mu_{tr}}{\rho} \right]_{w,air}^{(free)}} \quad (5)$$

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

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

The technique used to determine the BSF was acceptable, since the correlation between S4 and S4B is absolute, since they are directly proportional. Figure 2 shows that the application of the BSF factor was efficient, but the expanded

related uncertainty for these two 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 2.98 % in a high coefficient of variation.

## 5. CONCLUSIONS

The detectors calibration is extremely important for any measurement of dosimetry and protection against radiation. The readings IC were considered reliable, and also frequently 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 values adjustment found with the detector one meter and corrected by the inverse square law differs significantly from the measurements results with the section of the plane detector in the simulator patient or surface.

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 IC approach 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 IC detector is feasible and reliably replaces the TLD, eliminating even the uncertainty surrounding the

TLD 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 IC from the examination table, it is recommended to use an adequate backscatter factor.

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