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DEVELOPMENT AND CHARACTERIZATION OF A DOSIMETRIC DEVICE FOR EXTERNAL X AND GAMMA INDIVIDUAL MONITORING SYSTEM

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ABSTRACT

There is a tendency in the individual monitoring of always being involved with refinements that are able to effectively simulate the reality in terms of radiological conditions in which workers are subjected when exposed to external sources of ionizing radiation. Calibration Laboratories provide a set of irradiation conditions very well defined and standardized which can be used in studies of the physical phenomena based on the recommendations: International Commission on Radiation Units and Measurements - ICRU; International Commission on Radiological Protection - ICRP and International Organization for Standardization - ISO. However, many discoveries can be expected to contribute to ideals and satisfactory radiological conditions. Aiming to fill one of these gaps, a slab phantom, which is a human torso simulator, was used in order to assess the true personnel dose equivalent, $H_P(d)$, for photographic dosimeters. The slab was adapted and on it two dosimeters holders were built and placed inside the phantom, at a depth of 11 mm, from the front surface. Later, dosimeters were calibrated for the personal dose equivalent $H_P(10)$ at a depth d = 10 mm from the front surface. That is the position where the eletronic equilibrium of the dosimetric system for radiation strongly penetrant occurs. Thus, it was possible to evaluate the dose considering the influence of the backscattering and absorption of ionizing radiation produced by the human body. The calibration curves for the personal dose equivalent $H_P(10)$ were obtained from the data in the experiment when tested at doses from 0.2 to 50 mSv a ^{60}Co and ^{137}Cs radioactive sources, and X-ray beam on the wide (W) and narrow (N) spectra quality, as described by ISO 4037-1. The irradiation procedure with the dosimetric device will enable, among other applications, to test and calibrations for the purposes of scientific research and service to society.

1. INTRODUCTION

The European Union, through the Council Diretive 96/29/Euratom(1), has adopted the "new" concept of quantities for radiation protection developed by ICRU between 1985 and 1993(2) and, because of these measures being taken nationally, calibration laboratories should be able to calibrate dosimeters in terms of new operational quantities. In Brazil, provisionally, the individual monitors are calibrated in the quantities individual dose, H_x, with individual dosimeters calibrated in terms of air kerma as basic guidelines for radiological protection CNEN-NN-1.3(3), however, it is recommended to use the new quantities. For strongly

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penetrating radiation the operational quantity indicated for individual monitoring is the equivalent of personal dose $H_P(10)$, and, for weakly penetrating radiation is $H_P(0.07)$.
According to the international standard ISO 4037-3[4], the conventionally true value of $H_P(10)$ is based on air free kerma, K_a, by applying conversion factors, h_{pK} (10; E, α), K_a to $H_P(10)$. These coefficients are set to mono direction photon radiation and mono energetic energy incident, E, to dosimeters positioned over a slab phantom, and for various angles of incidence, α, between the field mono directions photons and the normal to the surface of the front face of the slab phantom . They are obtained in the ICRP Publication 74[5] and the ICRU report 57[6], further detailed in Ankerhold catalog[7].
Conversion coefficients are strongly dependent on photon energy and in particular for low energy photons. The ISO 4037-3[4] provides conversion coefficients for the reference radiation photons as specified in ISO 4037-1[8]. The spectral distributions with respect to the same radiation quality, if X-rays are produced by different devices and because of the different density air always show minor differences. Due to the high energy dependence of conversion coefficients for mono energetic low power, especially for grades with average radiation photons of energy less than 25 keV, small spectral differences can produce variations in the conversion coefficients on the same quality of X rays, which differ from 10% to 90%. Thus, conversion coefficients for determining $H_P(10)$ should not be applied for the purpose of calibration spectra using low energy photons.
Two solutions are possible to determine the true value conventionally $H_P(10)$. The first possibility is that the correct conversion factors are determined by measuring the spectrum generated by X-ray machines used for calibration, requiring a spectrometer for photons, which is expensive and sophisticated. And a secondary standard ionization chamber to directly measure $H_P(10)$ within the slab phantom.
This study aimed to develop an $H_P(10)$ phantom, whose characteristics are presented in the next section. It shows the calibration results in $H_P(10)$ phantom to ISO qualities of radiation series narrow and broad spectrum, and the comparison with the calibration phantom in the slab, according to ISO recommendation, which is performed with the dosimeter placed on the phantom slab and using the conversion factor for the extent in depth, for the same radiation qualities.

2. $H_P(10)$ PHANTOM

$H_P(10)$ phantom was designed to evaluate the personnel dose equivalent, $H_P(10)$, from the dosimeter conventionally inserting the true position of the evaluation of dose as shown in Figure 1. This object is a part for evaluating the dose. To this, were constructed in the center of the phantom, two cavities with covers, for the purpose of inserting photographic dosimeters. The other part, called backscattering portion is composed of a parallelepiped filled with water, simulating a human body for calibration purposes.

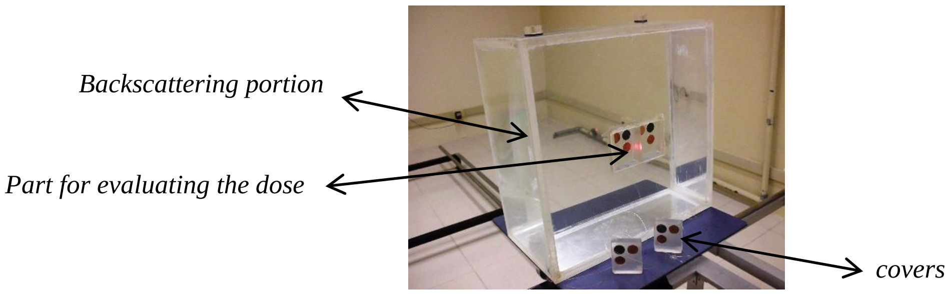

Figura 1: $H_P(10)$ Phantom.

The part of backscatter is similar slab phantom with dimensions of 300 mm x 300 mm x 150 mm, composed of walls PolyMethyl MethAcrylate (PMMA) and filled with distilled water. What differs from a slab phantom is, only the front wall of the object, or part of the dose evaluation, which was replaced by another kind of wall with the same thickness. In this wall were constructed with two cavities, and the cavities with dimensions of 80 mm x 50 mm x 11 mm and of the same material phantom. Cavities and covers were built three cells for fixing metal filters of a kind commonly used in photographic dosimeters door. A filter is lead (Pb), 0.8 mm thick, and the other two filters are copper, and 0.5 mm (0.5 Cu) and a thickness 0.1 mm (0.1 Cu) to the other. A region without filter is also considered to evaluate the dose.
The individual monitors (photographic dosimeters) were used in this study dosimetric films trademark of Agfa-Gevaert, Agfa personal monitoring type, measuring 33 mm x 45 mm x 1 mm, containing two films, one low and one high sensitivity.
For radiation dosimeters the following range and X radiation sources were used:

1. ^{60}Co source - 17.17 GBq in 07/10/1998, IPEN / CNEN manufacturer, 616/CoS132 model;
2. ^{137}Cs source - 444 GBq in 13/05/2003, JL Shepherd & ASSOCIATES manufacturer, 28-8A/10354 model;
3. X-ray, Pantak manufacturer, HF-320, 3 mm Be inherent filtration of the tube, voltage range 5-320 kV, current range from 0.5 to 30 mA, rotating anode power and size of 3.2 kW focal point 1.2 and 3 mm.

Two procedures were performed to calibrate dosimeters. The first was recommended by ISO(4) using the slab phantom, and the second, using $H_P(10)$ phantom; then the results were compared.
In Figure 2, called experimental arrangement 1, can view the slab phantom with three door dosimeters fixed on the front surface (yellow boxes containing metal filters), and the source of ^{60}Co. This arrangement is also exposed to the source of ^{137}Cs and the X-ray machine in the energies 45-164 keV, with narrow and wide spectrum.

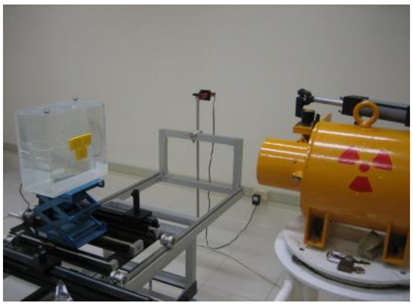

Figura 2: Experimental arrangement 1 - slab phantom.

Another procedure was performed with $H_P(10)$ phantom, being called experimental arrangement 2. In this arrangement, only the changed position of the dosimeters were placed on the internal surface of the slab phantom at a depth of 10 mm from the front surfasse, in other words, in the position where it should find the true value of the conventional dose, the simulation of the real interaction of ionizing radiation with phantom in terms of scattering and absorption. The arrangement is subjected to the same irradiation conditions.

In both experimental arrangements, around 200 (two hundred) dosimeters were irradiated with doses ranging from 0.2 to 50 mSv by γ ^{60}Co and ^{137}Cs beams and X-ray beam ISO the following qualities: N-60; N-100; N-150; N-200; W-60; W-80; W-150 and W-200[8].

The measuring system used to perform the dosimetry consisted of an electrometer, NE2670 model, 148 series and a 600cc ionization chamber NE2575C model, 518 series, polarity -250V, both manufactured by Nuclear Enterprises (NE).

Before any procedure, the measures system for dosimetry was placed in arrays 1 and 2, the test point of the radiation field. The test point is defined as the point in the radiation field in which the real value of the quantity $H_P(10)$ is evaluated (IEC / FDIS 61066, 2006)[9]. Thus, this system was obtained kerma rate of air, which multiplied by conversion coefficients, $h_{pK}(10; E, \alpha)$ was converted to $H_P(10)$ for each energy irradiation. Then, the front surface of the phantom was placed in the same test point for radiation.

The test point is located in the geometric center of the arrangement having been used in electronic equilibrium condition. According to dosimeters calibration procedure ISO[4] the phantom must be placed at 1m away from the radiation source, in this paper sources of ^{60}Co and ^{137}Cs, and 3.4 m away from the X-ray machine.

Assays were performed in controlled temperature and pressure 20 ± 2°C and 101.3 kPa, respectively.

Subsequent to irradiation, the dosimeters were transported to the Radiological Protection Laboratory, where the films were processed and disclosed in a dark chamber with controlled temperature and humidity, 20 ± 2°C and 36 ± 3%, respectively, and placed in a kiln. The evaluation of optical densities was performed in the photoelectric densitometer Macbeth, TD931 model.

The photographic dosimeter response is obtained in terms of optical density. Thus, the method for evaluating dose consisted of the linear combination in terms of apparent dose. This method is based on a simple model proposed by Borasi et al.[10] for the behavior of the film of the dosimetric response as a function of the outdoor air kerma (K_a) which is adapted to the personal dose equivalent (H_P) is described by equation 1.

$$D_{ij} = \gamma_{ij}\left(1 - e^{-\gamma'_{ij} H_P}\right) \quad (1)$$

Where: D_{ij} is the net optical density produced by the power of order "i" in order filter "j"; γ_{ij} is the optical density saturation energy produced by the "i" in the filter "j" and γ'_{ij} is the slope of a tangent to the curve at the point (i, j).
Through a combination of linear algorithm and based on the optical densities obtained from irradiated films was obtained optical density saturation of the film chosen as reference for others, γ_{ij}. This is the maximum optical density of the film, which remains unchanged at a constant value even with increasing dose. For the most sensitive film, the film selected as reference, the calculated saturation density was 9,02 and less sensitive film was 15,01. The algorithm calculates the maximum optical density that can reach saturation, thus increasing the linear region of the characteristic curve of the film, which is the region of interest for dosimetry.
Since the response of the film in terms of optical density does not present linearity with respect to dose, the characteristic curves are linearised by normalization with respect to a suitably chosen reference curve (filter and energy: under the lead of the energy filter and ^{60}Co) as described above. From there, the optical densities are converted, as is generally known as, apparent dose "DA"[(11)].
The apparent dose is related to the $H_P(d)$, according to equation 2.

$$DA = K \times H_P \quad (2)$$

Where K is the slope for readings on each filter, obtained by a linear fit for each calibration power value using the response of the dosimeter under the lead filter ^{60}Co.

3. RESULTS AND DISCUSSION

Once properly processed photographic dosimeters provide optical densities of each region of the films and a set of curves was built relating the net optical density (D_{ij}) movie with $H_P(10)$ personal dose equivalent for each energy E_i. Where the constant " γ_{ij} and γ'_{ij} " have the "i" associated with the energy of the radiation and the "j" associated with the filter region; Thus, for each j scan area of filters for each type emulsion (more sensitive or less sensitive).
As dosimeters are constituted of two layers with different sensitivities of emulsions for evaluation of optical density occurs when the most sensitive film is fully sensitized, i.e., at any dose, the result of the optical density is in the saturation region then using the least sensitive film to evaluate the optical density caused by that dose.
The Figures 3 and 4 refer to the characteristic curves of the films subjected to W60-energy (45 keV) and ^{60}Co (1250 keV), respectively, showing the results of optical densities obtained from more and less sensitive emulsions only in the region filter of lead (Pb) and $H_P(10)$ strip of 0,2 to 50 mSv and arrangements 1 and 2.

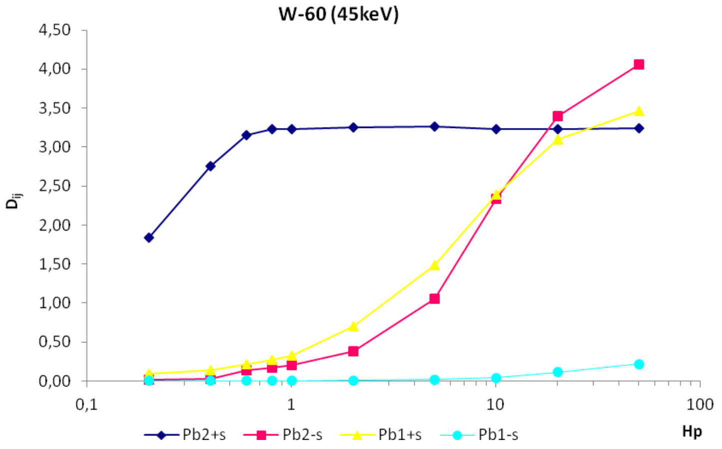

Figure 3: D_{ij} as a function of $H_P(10)$ in the filter to lead the energy of 45 keV - more sensitive and less sensitive emulsion, for the arrangements 1 and 2.

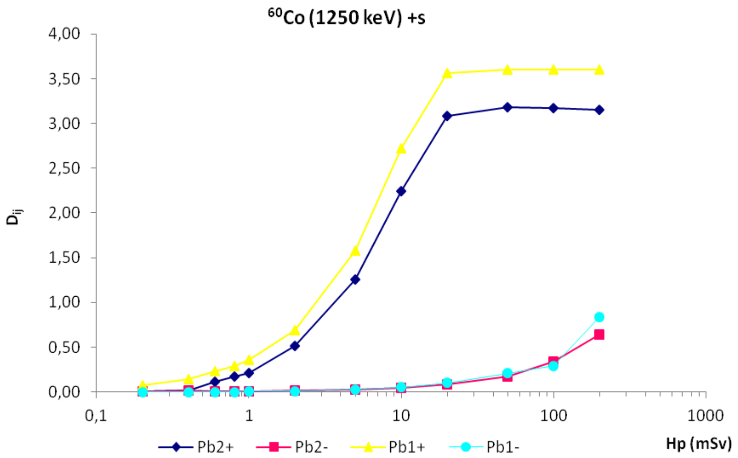

Figure 4: D_{ij} as a function of $H_P(10)$ in the lead filter to the energy 1250 KeV - more sensitive and less sensitive emulsion, for the arrangements 1 and 2.

Figure 3 shows the results of the optical densities of the films emulsion more or less sensitive, lead from the filter area (Pb), depending on the dose and the obtained experimental arrangements 1 and 2, only for the irradiation with energy 45 keV. Data obtained in the arrangements for the emulsion film more and less sensitive Comparing (Pb1 + and Pb1-) may

be noted that in the arrangement 1 the optical densities from the most sensitive emulsion (Pb1 +) had similar behavior a normal characteristic curve of a film dosimetry, where the optical density is presented in the first base region + veiling, extending by a linear region, called region of interest until reaching the saturation region, a region where, although dose increases, the optical density remains unchanged. As for the optical densities from less sensitive emulsion (Pb1-) one can see that there was almost no awareness, that is, for any dose, the optical densities remained in the base region + veiling, which indicates that the evaluation of the dose should be analyzed the most sensitive emulsion film (Pb1 +).
On the other hand, analyzing the arrangement 2, it is observed that the awareness of the dosimeter was higher because there was the contribution of the spread of ionizing radiation due to the fact that radiation through a wall of 10 mm equivalent material to human tissue. Thus, unlike the arrangement 1, it is observed that the optical densities from the most sensitive emulsion (Pb2 +), for nearly all doses present in the region of the characteristic curve, called the saturation region. Thus, doses must be evaluated from the optical densities less sensitive emulsion film (Pb2-), which have similar behavior at normal characteristic curve of a film dosimetry.
What has happened in the arrangement 2 is due to the fact that there photographic emulsion as in the presence of silver bromide, which does increase the effective atomic number of the means of interaction of radiation at low energy incident radiation ($E \leq 100$ keV), where absorption by photoelectric effect is predominant and has a direct dependence on the atomic number, the electrons released in the interaction point develop a rapid process of energy transfer. And as the cross-section for the photoelectric effect varies rapidly with energy, this causes a strong energy dependence of the photographic dosimeter also joins the fact that the dosimeter is located in the depth of occurrence of electronic equilibrium.
It has been found that for all rays with energies up to 164 keV, used in this study could be found that there was this same effect, which demonstrates the high energy dependence of the dosimeters for low power.
In Figure 4, where the dosimeters were irradiated with energy 1250 keV (high energy), there were behaviors equivalent to both experimental arrangements. The same happened for dosimeters irradiated with energy of 662 keV.
H_P phantom was possible to prove, even more surely, the strong energy dependence of the dosimetric system for low energy photons. According to several researchers [12 to 15] should not use the conversion coefficients in the low energy procedures recommended in ISO 4037-3, as there are differences in the spectral radiation fields generated by different X-ray equipment and these differences cause great percentage changes in the coefficients. Using the H_P phantom is a more appropriate procedure to calibrate dosimeters, since using an ionization chamber, commercially available, called H_P camera and developed in the German Laboratory - Physikalisch Technische Bundesanstalt (PTB) [16], can be dispensed with using conversion factors of air kerma for H_P.

3. CONCLUSION

Based on the results obtained, we can conclude that the $H_P(10)$ phantom can be used for calibration and testing for research and services. Importantly, the evaluations of the doses received by workers should be, and adapted to the quantities recommended by the International Commissions, are also updated the methods used in dosimeters calibration. Thus, $H_P(10)$ phantom is presented as a solution for eliminating conversion coefficients at low energies. He confirms that, increasingly, new studies in dosimetry and improvement of relevant laws are carried out.

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