Determination of the Effective Energy in X-rays Standard Beams, Mammography Level

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Abstract. The X-rays beams used in diagnostic radiology are heterogeneous. This means that, in a radiological beam, it can be found photons with different energies. Because of that is common to work with the concept of effective energy. In this study the effective energy of an X-rays system used in instruments calibration was determined, as part of the mammography radiation qualities establishment. The procedure presented here was developed based on information found in the literature. The X-ray mass attenuation coefficients for aluminum, given by NIST website, were used and the mathematical adjusts were done using the Origin® 8.0 program. The results are part of the mammographic X-rays beams characteristics determination and it is important to keep the quality of this reference system.

1 Introduction

The X-rays beams used in diagnostic radiology are heterogeneous. This means that, in an X-ray beam, can be found photons with different energies. This phenomenon happens because, in the interaction of the electrons with the anode, both characteristic and Bremmstrahlung radiation may occur.

Because of this it is common to work with the concept of effective energy, defined as the energy of a heterogeneous beam with the same HVL (half-value layer) as a homogeneous beam[1].

To determine the effective energy is necessary to use equations and values available in literature[2,3].

The effective energy determination is an important issue for the characterization of radiation qualities established in X-ray systems used to instruments calibration.

2 Materials and Method

2.1 Materials

The effective energy was determined for the mammography radiation qualities established in a Pantak/Seifert X-rays system, with tungsten (W) target (anode), inherent filtration of 0.138 mm of aluminum (Al)[4] and a window of 0.8 mm beryllium (Be)[5]. The mammography qualities were already established in this system using Al and molybdenum (Mo) filters as additional filtration. The tube voltages used were 25 kV, 28 kV, 30 kV and 35 kV. The mathematical analysis was done using the Origin® 8.0 program.

2.2 Methods

The first step in this procedure was to determine the attenuation coefficient (μ) of the material used to determine the HVL (in this case, aluminum), for each established radiation quality. The equation 1 was used in this case.

$$I = I_o e^{-\mu x} . \quad \textbf{(1)}$$

I_o is the beam intensity without additional filtration, and I is the intensity after the insertion of attenuate material with thickness x.

From the equation 1, when is using the HVL values, and applying the natural logarithm, the μ value can be determined using the equation 2.

$$\mu = \frac{\ln 2}{HVL} . \quad \textbf{(2)}$$

The next step was to obtain the ratio μ/ρ, in which ρ is the material specific mass. It can be found in some books or specifics tables[2]. At National Institute of Standards and Technology (NIST)[3], it is presented the graphic that relates the ratio μ/ρ with the effective energy. This graphic is shown at figure 1.

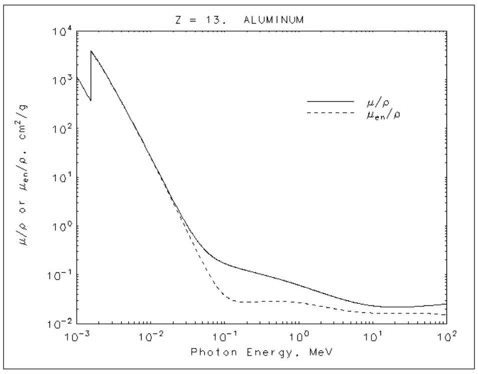

FIG. 1. Graphic that relates μ/ρ, cm²/g, with photon energy in MeV (continuous line).

The NIST also provides the values used to build this graphic, which makes the link between the ratio μ/ρ and the respective effective energy. Comparing the calculated ratio with the values given by NIST it is possible to determine the effective energy for each one of the established radiation qualities.

3 Results

The mammography radiation qualities were established using the HVL values presented by the German Primary Standard Dosimetry Laboratory *Physikalisch-Technische Bundesanstalt* (PTB). The calculated μ values (ln2/HVL) were divided by the Al specific mass (ρ = 2.699 g/cm³). The results (μ/ρ) were compared with those presented by NIST[3]. To find the effective energy values related to the μ/ρ values calculated in this work it was developed a special procedure.

Usually in the range of mammography beams, the photon energy is between 14 keV and 25 keV[1,6]. In the figure 1, the graphic section referent to this energy shows a linear tendency. Using the values which are in this part of the graphic(figure 1), it was built another graphic, figure 2. Adjusting the values it was drawing the curve in order to obtain the energy values.

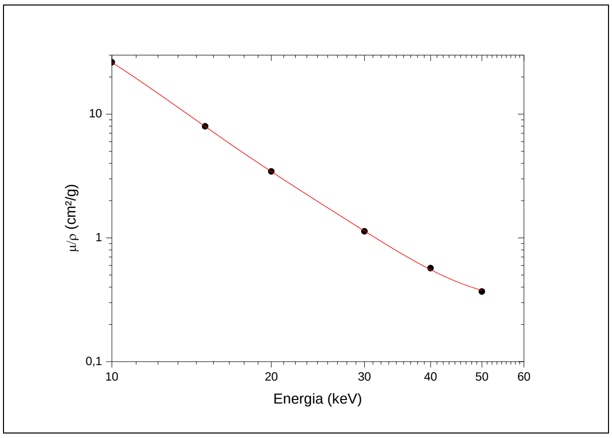

Fig. 2. Fit linking the points obtained from the table given by NIST

As the both axes are in logarithmic scale, it is not possible to find a straight line doing a linear fit, because of that the option “ExpDec2” of the Origin® 8.0 it was used to fit the curve. The equation found after the adjustment was:

$$y = A1 \times e^{-\frac{x}{t1}} + A2 \times e^{-\frac{x}{t2}} + y_0. \tag{3}$$

The adjusted parameters values are shown in table 1:

Table 1. Parameters values of the equation given by Origin® in the exponential fit

Parameter	Value	Uncertain
y_o	0.2976	0.0277
A1	633.1038	44.9821
t1	2.77845	0.08632
A2	27.84462	3.97565
t2	8.5271	0.4431

Knowing the parameters of the equation 3 it is possible to determine the effective energy. However, this equation is not simple to solve. The best way to obtain the energy value is fitting the graphic, in the program Origin®, using a great number of points (about 50000). Therefore, using the *Data Reader* tool, is possible to obtain the *x* and *y* values at a specific point just putting the mouse pointer over the curve.

Using this procedure it was possible to determine the effective energy values. The obtained results, for entrance (WAV with Al and WMV with Mo) and attenuated (WAH with Al and WMH with Mo) radiation qualities, are shown in tables 2, 3, 4, and 5

Table 2. Ratio μ/ρ and effective energy values for WAV radiation qualities

Quality	Voltage (kV)	Additional Filtration (mmAl)	HVL (mmAl)	μ/ρ (cm²/g)	Effective Energy (keV)
WAV 25	25	0.57	0.35	7.338	15.4 ± 6.0
WAV 28	28	0.57	0.40	6.421	16.1 ± 6.3
WAV 30	30	0.58	0.43	5.973	16.5 ± 6.4
WAV 35	35	0.62	0.51	5.036	17.5 ± 6.8

Table 3. Ratio μ/ρ and effective energy values for WMV radiation qualities

Quality	Voltage (kV)	Additional Filtration (mmMo)	HVL (mmAl)	μ/ρ (cm²/g)	Effective Energy (keV)
WMV 25	25	0.07	0.36	7.134	15.6 ± 6.0
WMV 28	28	0.07	0.37	6.941	15.7 ± 6.1
WMV 30	30	0.07	0.38	6.758	15.8 ± 6.2
WMV 35	35	0.07	0.41	6.264	16.3 ± 6.3

Table 4. Ratio μ/ρ and effective energy values for WAH radiation qualities

Quality	Voltage (kV)	Additional Filtration (mmAl)	HVL (mmAl)	μ/ρ (cm²/g)	Effective Energy (keV)
WAH 28	28	0.57 + 2	0.88	2.918	21.2 ± 8.2
WAH 30	30	0.58 + 2	0.97	2.648	22.0 ± 8.5
WAH 35	35	0.62 + 2	1.21	2.122	23.8 ± 9.3

Table 5. Ratio μ/ρ and effective energy values for WMH radiation qualities

Quality	Voltage (kV)	Additional Filtration (mmMo)	(mmAl)	HVL (mmAl)	μ/ρ (cm²/g)	Effective Energy (keV)
WMH 25	25	0.07	2	0.56	4.586	18.1 ± 7.0
WMH 28	28	0.07	2	0.61	4.210	18.6 ± 7.2
WMH 30	30	0.07	2	0.68	3.777	19.4 ± 7.5
WMH 35	35	0.07	2	0.93	2.761	21.6 ± 8.4

4 Conclusion

The procedure used allowed to obtain the effective energy values however the uncertainties are high (about 40%). This happened because uncertainty values used for the combined uncertainties calculation (those given by the program Origin®) are also very high.

In this case it was not performed a set of measurements, so it was not possible to determine the coverage factor. Thus, there has been used k = 2, because this value is more commonly used, representing 95 % of level of confidence.

The determination of these values was so important to cover all factors needed to have this beam well known, increasing the quality and reliability of the calibrations made in this system

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