Measurements of half value layer using different detectors and calculations of effective energies for low energy X-ray experimental setup

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Introduction

The half value layer (HVL) is the first, basic and key parameter that should be estimated for a newly constructed experimental system. This value is necessary to calibrate any detector and it can then be used in the dosimetry process [1]. Usually, the calibration process is done by Secondary Standards Laboratory (SSL) in terms of kerma or absorbed dose [1,2]. Effective energy is the second essential factor to describe a fully experimental setup [3]. Additionally, [4] showed that HVL values can have different numbers depending on the absorbed material, which was set at a standard distance of 50 cm from the X-ray tube during HVL measurement. Although aluminium is the most common substance that is used as an absorbent in measurements of HVL value, especially for low energy X-rays, but sometimes copper is also applied, mainly for high energy photons [5] and usually above 100 kV in the X-ray tube [4]. The HVL values also depend on the energy of the X-ray beam [6]. The measurement of HVL values in this study had two aims. The first intention was to prepare a newly built experimental system to start the dosimetry process, where the first step is the calibration of the detector by SSL. The second purpose was to compare the HVL values obtained by means of different detectors. To achieve these goals, four types of detectors were used. Additionally, HVL values were determined for X-ray beam both with and without additional filtration. The HVL values and effective energies are new information for the low energy X-ray experimental system that is placed at Jan Kochanowski University in Kielce, Poland.

Methods

Experimental setup

The first part of the experimental system was an X-ray tube (X-ray Diffraction type no. 9430 922 00291) and generator (no. PW 3830), which was obtained from PANalytical, Holland. The experimental system was also described in [7]. Filters were set at the output of the X-ray beam, which were made of different materials i.e., zirconium (Zr), vanadium (V), iron (Fe), nickel (Ni) and were also created by the PANalytical company. Fig. 1 shows the X-ray tube scheme. The second part of the experimental setup was a metal table on which an aluminium rail was placed with manually sliding footbridges that were equipped with a series of drilled holes.

Half value layer measurement method

HVL measurement method has been taken from [4,7]. The following four types of detectors were used to measure HVL values:

- Markus type 34045 without a build-up cap with electrometer Unidoswebline Universal Dosimeter (PTW, Germany),
- Farmer type 30013 without a build-up cap with electrometer Unidoswebline Universal Dosimeter (PTW, Germany),
- Mult-O-Meter no.1 (Unors Instruments, USA),
- Gafchromic EBT2 film (Ashland, USA).

The HVL value was determined according to the following equation [8]:

\[ HVL = \frac{t \cdot \ln \left( \frac{2}{E_0} \right) - t_0 \cdot \ln \left( \frac{2}{E_0} \right)}{\ln \left( \frac{E_0}{E} \right)} \]

where \( E \) presents the values read from detectors and bottom index determined the values read without absorbent (bottom index was 0), greater than \( E_0/2 \) (bottom index was a) and lower than \( E_0/2 \) (bottom index was b). In addition, \( t \) was the thickness of absorbent and its bottom index was associated with the value of \( E \) with the same index. In practice, HVL1 i.e., first half value layer and HVL2 i.e. second value layer are used. In the case of Gafchromic film, the net optical density (NetOD) values are determined [9, 10] and the average pixel values were read for the red channel of scanned films [11] using ImageJ program [12].

Effective energy calculation

The effective energy calculation procedure was taken from the publications [3, 13]. For this purpose, the measured HVL values were used and the attenuation coefficient was estimated from the equation concerning declining the intensity of X-ray radiation after passing through material with the specified thickness [14]. Effective energy was determined based on this coefficient and by using table a from the dataset of [3, 15].

Results

Table 1 shows HVL1 and HVL2 results calculated using data from four detectors irradiated at 60 kV and 50 mA. Table 2 shows HVL1 calculated using data from detectors irradiated at 30, 40, 50, 60 kV and 30 kV filtered by vanadium filter and effective energies. Table 3 shows HVL1 calculated using data from the ionisation chamber Farmer 30013 irradiated at 60 kV plus various filters and effective energies.

Table 1. HVL1 and HVL2 calculated using four detectors

<table>
<thead>
<tr>
<th>Detector Type</th>
<th>HVL1 (mm Al)</th>
<th>HVL2 (mm Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markus 34045</td>
<td>3.19</td>
<td>2.51</td>
</tr>
<tr>
<td>Farmer 30013</td>
<td>3.51</td>
<td>2.83</td>
</tr>
<tr>
<td>Mult-O-Meter</td>
<td>3.43</td>
<td>2.75</td>
</tr>
<tr>
<td>Gafchromic EBT2</td>
<td>3.75</td>
<td>3.07</td>
</tr>
</tbody>
</table>

Table 2. HVL1 calculated using four detectors of different spectrum of X-ray beam.

Table 3. The HVL1 values and effective energies calculated for voltage 60 kV and different filters that were set on an X-ray tube using data read from ionisation chamber Farmer 30013 without a build-up cap.

Conclusions

The low energy X-ray experimental setup at the Institute of Physics of Jan Kochanowski University in Kielce, Poland was used to determine HVL and effective energies. Four types of detectors were used: Mult-O-Meter no.1, Farmer type 30013, Markus type 34045, Gafchromic EBT2. HVL values were estimated for various voltage settings in an X-ray tube, both when the X-ray beams were filtered and when they were not. In summary:

- the type of detector is important when determining the HVL values. The measurements made with different detectors show various HVL values,
- the HVL and effective energies increase with increasing voltage in the X-ray tube in the range of 30 kV to 60 kV,
- the HVL and effective energies increase by 1.7 times when an X-ray beam is filtered by a V filter at 30 kV,
- the effective energies had identical values when V, Zr, Fe filters were used at 60 kV.

Literature cited

[2] Iba. Calibration services offered by the Dosimetry Laboratory of IBA Dosimetry.