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A simple method for evaluation of half-value layer variation in CT equipment

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Abstract

Tandem systems, each formed by a pencil ionization chamber with and without a specific covering, were developed and tested in standard radiation beams. These systems were designed to be used in computed tomography radiation beams, where the half-value layer (HVL) determination is not an easy task. The behaviour of the tandem systems in diagnostic radiology showed the possibility of their use to confirm HVL values previously determined by the conventional HVL measurement method in quality control programmes. These systems also have other advantages: low cost, easy application and quick measurement procedure.

1. Introduction

Half-value layer (HVL) measurement in computed tomography equipment is not an easy task because of the x-ray tube rotation. For the conventional method of HVL determination, the tube rotation must be interrupted, which demands a technician intervention in the equipment mode (Kruger *et al* 2000, Hill 1999).

Unlike the quality assurance programme for conventional diagnostic equipment, where the HVL test is mandatory, in computed tomography equipment only the manufacturer performs this test, and the initial value is not usually checked again during the equipment life time (Kruger *et al* 2000). A simple method to verify the long time constancy of the HVL initial measured values could, however, be very useful, and it may be used as a preventive method for the indication of equipment malfunctions. Therefore, this study had the objective of development of a system that could be applied for HVL evaluation in computed tomography equipment. The developed system is simple, easy and fast to use; therefore, it can be recommended for routine quality control programmes.

Some other noninvasive techniques of HVL measurements were developed by Kruger *et al* (2000). Those techniques were simpler but still similar to the conventional method for HVL determination in terms of time consumption, because of the need of several filters to obtain an attenuation curve. The idea of the study in the present work was completely different: it involves the development of a tandem system with the pencil ionization chamber associated with coverings of different materials that may be used in a very fast and simple way. The association of the ionization chamber with each one of the coverings forms systems, where each one has a special energy dependence response. The utilization of the pencil ionization chamber is simpler because this chamber is largely used in quality assurance programmes in computed tomography, and cheaper because the acquisition of other instruments will be unnecessary. The chamber coverings used in this study can be manufactured very easily.

The utilization of dosimeters with different energy dependence characteristics, composing a tandem system, to verify HVL values previously determined, is a common practice in several other kinds of radiation beams. The first tandem systems were formed by thermoluminescent dosimeters (Gorbics and Attix 1968, Spurny *et al* 1973, Da Rosa and Nette 1988, Miljanie *et al* 1999). The radiation metrology group of the Instituto de Pesquisas Energéticas e Nucleares (IPEN) developed other kinds of tandem systems using ionization chambers (Caldas 1991, De Souza *et al* 1996, Costa and Caldas 2003a, 2003b). Studies were already performed using thermoluminescent dosimeters as a tandem system in computed tomography (Saez Vergara *et al* 1999, Tsai *et al* 2003). The main disadvantage of the thermoluminescent dosimeters as tandem systems is that they do not provide direct results as the systems composed of ionization chambers do.

Even though a conventional tandem system is composed of two different dosimeters, the system proposed in this study can also be called a tandem system because it is formed by an ionization chamber with and without a covering, with distinct energy dependences. The difference in the energy dependence is a consequence of the interaction of the radiation with the different covering materials. By passing through the coverings, the radiation beam is modified due to absorption and scattering of the incident photons. The main interaction processes of the ionizing radiation with matter, which are the photoelectric effect and the Compton effect, depend on various factors, such as the beam energy and the absorber atomic number. Therefore, the utilization of coverings of different materials induces distinct energy dependence in the ionization chamber behaviour (McKetty 1998).

2. Materials and methods

For this study, nine different coverings, of three distinct materials, were manufactured: three of polymethyl methacrylate (PMMA) (with wall thicknesses of 5, 15 and 25 mm), three of aluminium (with wall thicknesses of 1, 3 and 5 mm) and 3 of copper (with wall thicknesses of 0.051, 0.152 and 0.254 mm), as can be seen in figure 1. All coverings present adequate dimensions to be used with the Victoreen pencil ionization chamber, model 660-6. This chamber was used in this study without its original Victoreen pre-amplifier, but coupled to a PTW electrometer, model UNIDOS 10001. The chamber is unsealed, and it presents 3.2 cm^3 of sensitive volume and 10 cm of sensitive length. The measures of this ionization chamber are proportional to the irradiated length.

An industrial x-ray system *Pantak/Seifert*, model ISOVOLT 160HS, was used for most of the tests in this work. This equipment operates from 5 to 160 kV. Diagnostic qualities defined by the *International Electrotechnical Commission*, IEC 61267 (1994), were established in this system, and their parameters are listed in table 1. The reference system for these qualities was a parallel-plate ionization chamber with 1 cm^3 of sensitive volume, PTW, model 77334, with a PTW electrometer, model UNIDOS 10001. This chamber was calibrated by the German primary standard laboratory *Physikalisch-Technische Bundesanstalt* (PTB).

Figure 1. Nine coverings developed to be used with the Victoreen pencil ionization chamber, made of copper, aluminium and polymethyl methacrylate.

Table 1. Diagnostic radiology qualities, direct beams, with 2.5 mmAl total filtration, at the *Pantak/Seifert* x-ray equipment.

Radiation quality	Voltage (kV)	Half-value layer (mmAl)	Effective energy (keV)
RQR7	90	2.95	33.05
RQR8	100	3.24	34.40
RQR9	120	3.84	37.05
RQR10	150	4.73	40.75

For evaluation of the tandem system, several measurements were taken with the pencil ionization chamber with and without the different coverings in the standard beams listed in table 1. The tandem curves were obtained by the ratios of the measurements performed using the pencil ionization chamber with a covering (or without any covering) and the pencil ionization chamber with another covering.

3. Results and discussion

Measurements of the pencil ionization chamber with and without the different coverings were taken using the diagnostic beams listed in table 1. The reference quality for calibration of ionization chambers used in computed tomography dosimetry is RQR9 (120 kV) (IEC 61674 1997). Therefore, this study was performed using this quality and the adjacent qualities, using a voltage range from 90 kV to 150 kV. After measurements, the results in each case were compared, and figure 2 shows the tandem curves obtained by the quotient of the mean value of the ionization chamber with each covering in each radiation quality and the mean values of the ionization chamber without any covering for each radiation quality.

For the purpose of HVL evaluation, high inclination tandem curves are advantageous because they allow the differentiation of closer HVL values. Figure 2 shows that most of the curves can be used for HVL evaluation but the better ones are the curves obtained using the ionization chamber with a highly absorbing material covering. Except in the cases of the coverings of 0.051 mmCu and 5 mmPMMA, the differences in the measurement ratios of subsequent HVL values were always higher than 2%, being in some cases even higher

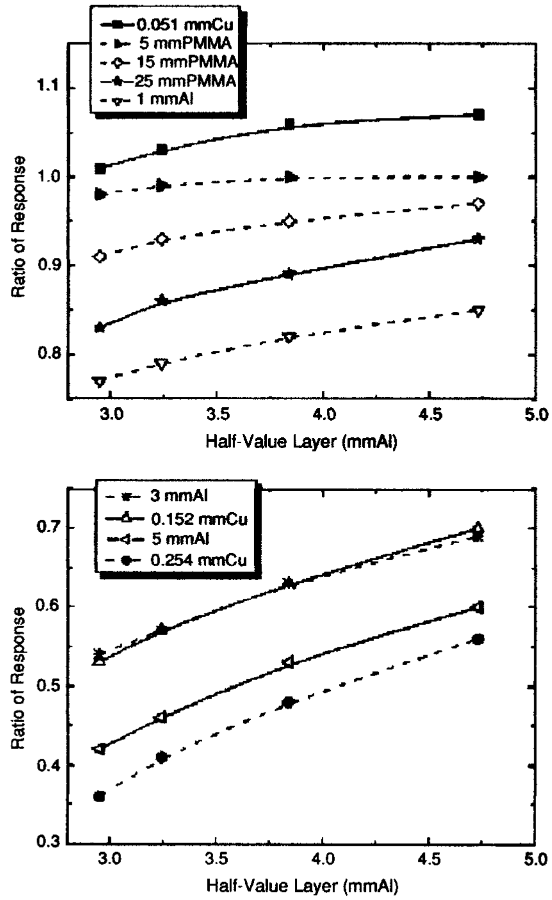

Figure 2. Tandem curves obtained by the ratios of the measurements performed using the ionization chamber with each one of the coverings described in the caption and the ionization chamber without any covering, in the diagnostic radiology qualities, at the *Pantak/Seifert* x-ray equipment.

than 10%. In the tandem curve using the covering of 0.051 mmCu, ratios above unity were obtained because the contributions of the scattered and backscattered radiations were greater than the absorption effect caused by the covering.

To form a good pair of chamber plus covering combinations, the ideal choice, in this case, is to use the chamber with a highly absorbing material covering (such as the 25 mmPMMA, or the 1, 3 or 5 mmAl, or the 0.152 or 0.254 mmCu coverings) and the chamber without any covering, or the chamber with a low absorbing material covering (such as the 5 or 15 mmPMMA, or the 0.051 mmCu coverings). Considering also other practical aspects, such as manufacturing simplicity and the covering dimensions, the best combination chosen in this study was the pair composed of the ionization chamber with the 5 mmAl covering and the ionization chamber with the 15 mmPMMA covering. The first covering (5 mmAl) is the most practical one among the highly absorbing material coverings because it is simpler to manufacture than the copper coverings, and it is not as thick as the PMMA 25 mm covering, which presents some difficulty to get positioned.

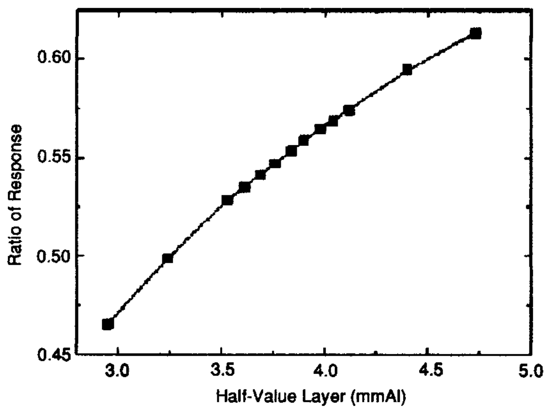

Figure 3. Tandem curves obtained by the ratios of the measurements performed using the pair composed of the ionization chamber with the 5 mmAl covering and the ionization chamber with the 15 mmPMMA covering, in radiation beams similar to the RQR9 radiation quality (120 kV), at the *Pantak/Seifert* x-ray equipment.

Table 2. Various radiation beams, 2.5 mmAl total filtration, with HVL values close to the HVL value of the RQR9 quality, at the *Pantak/Seifert* x-ray equipment.

Voltage (kV)	First half-value layer (mmAl)	Second half-value layer (mmAl)	Homogeneity coefficient
90 (RQR7)	2.95	4.62	0.64
100 (RQR8)	3.24	5.20	0.62
110	3.53	5.72	0.62
112.5	3.61	5.86	0.62
115	3.69	5.94	0.62
117.5	3.76	6.13	0.61
120 (RQR9)	3.84	6.31	0.61
122.5	3.90	6.37	0.61
125	3.98	6.53	0.61
127.5	4.04	6.65	0.61
130	4.12	6.78	0.61
140	4.40	7.27	0.61
150 (RQR10)	4.73	7.79	0.61

For a more detailed study, HVL measurements were taken in other non-standard radiation beams, shown in table 2. For the purpose of this study, the only relevant parameter is the HVL value, even if the radiation beams are not standardized. A complete tandem curve, shown in figure 3, was obtained with the pencil ionization chamber and the chosen pair of coverings in those radiation beams. With this pair of coverings, two more tandem curves can be obtained by the ratios of the measurements performed using the ionization chamber with each one of the coverings and the chamber without any coverings. Those curves are shown in figure 4. The utilization of more than one tandem curve can be helpful as a confirmatory method since they produce redundant results.

The uncertainties involved in the measurements with this proposed tandem system were determined by computing both type A and type B uncertainties, and a confidence level of 95% was considered (ISO 1995). The main factors affecting the estimated uncertainties were the

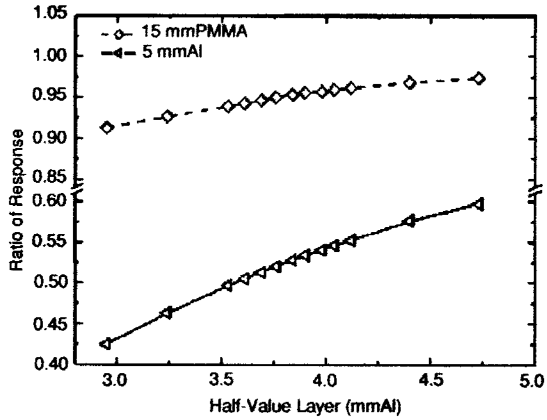

Figure 4. Tandem curves obtained by the ratios of the measurements performed using the ionization chamber with each one of the coverings described in the figure and the ionization chamber without any covering, in radiation beams similar to the RQR9 radiation quality (120 kV), at the *Pantak/Seifert* x-ray equipment.

statistical uncertainty associated with the measurements with the ionization chamber and the uncertainty of the electrometer. The expanded uncertainty was estimated as 0.45% for the diagnostic radiology. The uncertainties were apparently low because, once all measurements are relative, the uncertainties related to the reference systems were not included in those calculations.

The utilization of tandem curves is very simple. First, the HVL values must be determined by the conventional method. Subsequently, measurements with the tandem system are taken under the same conditions. The ratio of the measurements of the ionization chamber with the two different coverings will be considered as the reference value related to the HVL measured value. During the routine quality control tests, new measurements with the tandem system should be taken. Any relevant variation, in comparison with the reference value, indicates changes in the HVL value, and maintenance precautions should be provided. This method is, therefore, a very useful preventive method.

4. Conclusions

A tandem system composed of a pencil ionization chamber coupled to two different coverings was suggested and tested in standard radiation beams in the diagnostic radiology energy range. The behaviour of the system within the tests showed the possibility of its use for verification of the constancy of HVL values previously determined by the conventional method. For a complete study, the system was tested, with success, in non-standard radiation beams that cover in detail the diagnostic radiology HVL range.

The tandem system suggested in this work allows frequent confirmations of the HVL values for computed tomography equipment in quality control programmes. Even though the HVL measurement is not mandatory for computed tomography equipment, the precise definition of the radiation quality is a need for some dosimetric purposes, such as the calculation of patient effective doses.

Other advantages of the suggested tandem system are its manufacture facility, low cost, simplicity of use and fast measurement procedures. For all these reasons, the tested tandem system may lead other users to adopt a similar idea in their quality control programmes.

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