Non-invasive determination of the X-ray spectra and bow-tie filters in a CT scanner

PTB has its own medical CT scanner for research and development tasks in the field of dosimetry in CT. In the present report, experimental methods and theoretical calculations are presented with the aid of which the photon fluence spectra of the integrated X-ray tube and the geometry of the bow-tie filters have been characterized.

For 2010, the collective effective dose from computer-tomographic (CT) examinations per inhabitant amounted in Germany to approx. 1.1 mSv. This is approx. 61 % of the total collective effective dose by X-ray examinations [1]. These statistics show how important CT dosimetry has become. A usual method for the calculation of the organ doses of patients in the case of CT examinations is the application of Monte Carlo (MC) simulations which requires a detailed description of the components of a CT system. The technical documentations of the CT systems furnish some specifications such as, for example, the collimation, the diameter of the gantry and the distance between the X-ray tube and the detectors. Some scanner-specific data such as, for example, the X-ray spectra and the bow-tie filters, which are installed in each modern CT, are – however – kept secret by the manufacturers.

Within the scope of a research projects, methods and measurements for the characterization of the X-ray spectra and bow-tie filters of the CT scanners of the type GE-Optima 660 have been developed and performed. The most important details of the scanner can be found in the reference [2].

For the determination of the photon fluence spectra of the X-ray tube installed in the CT, measurements of the half-value layers in the service-mode control of the CT were carried out. Thereby, the rotation of the X-ray tube was stopped and the half-value layers for aluminium were measured without bow-tie filters. A spectrum with identical half-value layers was calculated using the "SpekCalc" [3] program. The spectrum calculated in this way provided a good approximation for the X-ray spectrum of the CT with an aluminium-equivalent inherent filtration.

To compensate for the smaller absorption of cylindrical objects in the boundary area of the CT gantry and to, thus, realize a uniform illumination of the detectors, special filters, the so-called bow-tie filters (BT), are mounted into the CT scanners. These filters are thin in their centre and their thickness increases symmetrically towards the periphery. In the past years, a method [4, 5] based on the comparison of calculated and measured air kerma profiles along the fan angles of the CT gantry (x-axis) has been developed for the characterization of bow-tie filters. In this work, this method was used and further developed.

The air kerma profiles along the x-axis with and without bow-tie filters were measured in the service mode of the scanner, see Figure 1. First of all, the measurement was performed without a bow-tie filter, then with the small filter and, finally, with the large filter. For this purpose, an ionization chamber of the type Radcal 10X6-0.6CT with a measuring volume of 0.6 cm^3 and a solid detector of the type RTI Dose Profiler were used. In contrast to the ionization chamber with an air kerma response which is (almost) independent of the photon energy, the solid detector shows a significant energy dependence of the response. The air kerma responses of the ionization chamber and of the solid detector as a function of the photon energy were determined in the ISO narrow-spectrum radiation qualities (20 kV to 300 kV) [6] and the special radiation qualities used at PTB (PTB AS series) using the PTB's primary air kerma standard. Figure 2 shows the normalized air kerma responses of the two detectors as a function of the photon energy.

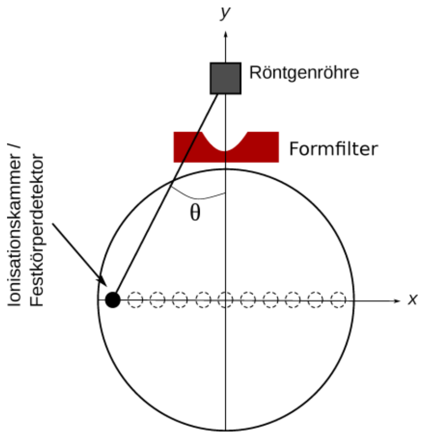

Fig. 1: Experimental set-up for the characterization of the bow-tie filters.

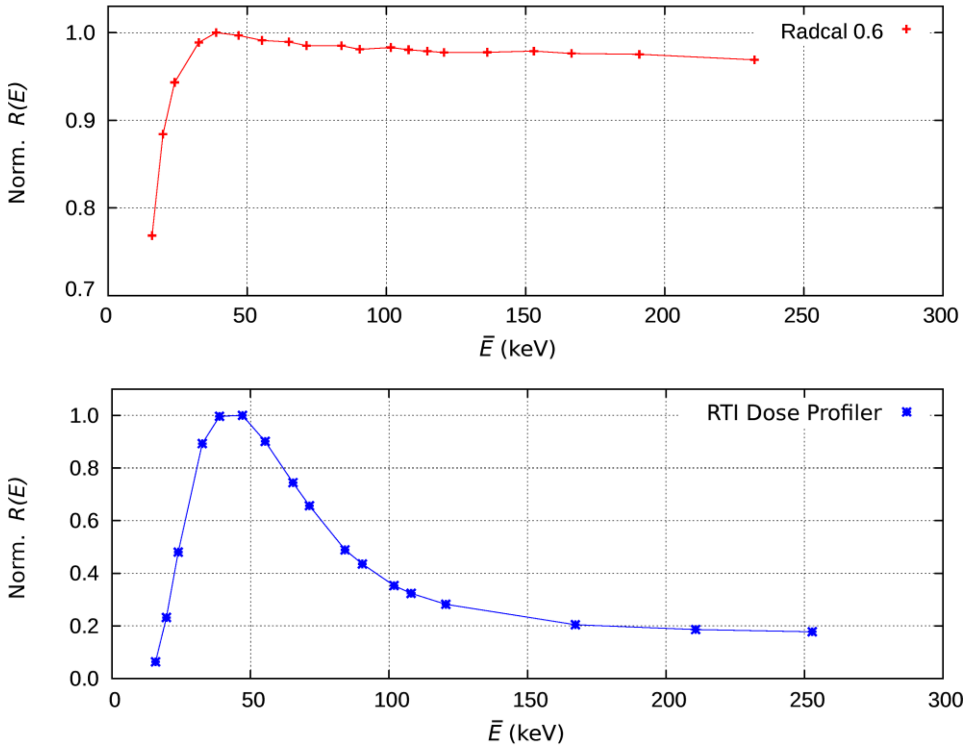

Fig. 2: Normalized air kerma response *R(E)* as a function of the mean photon energy *E* for the ionization chamber (top) and the solid detector (bottom). Normalization was performed to the maximum value of the corresponding response.

The aluminium-equivalent bow-tie filters were calculated in the following steps:

1. The ratio of the measured air kerma profiles with the bow-tie filter to the measured profiles without the bow-tie filter was calculated as a function of the fan angle θ. First of all, the energy dependence of the response of the solid detector was not taken into account:

$$\boldsymbol{\kappa}_{\text{experiment}}\,(\boldsymbol{\theta}) = \frac{\boldsymbol{K}_{\text{with BT}}(\boldsymbol{\theta})}{\boldsymbol{K}_{\text{without BT}}(\boldsymbol{\theta})}\,.$$

2. The air kerma profile was calculated for an arbitrary aluminium thickness x_{Al}. The following equation represents the theoretical ratio of the air kerma profiles with the aluminium thickness x_{Al} to the air kerma profiles without the thickness x_{Al}:

$$\boldsymbol{\kappa}_{\text{theory}}\,(\boldsymbol{\theta}) = \frac{\boldsymbol{K}_{\text{with Al-thickness}}(\boldsymbol{\theta})}{\boldsymbol{K}_{\text{without Al-thickness}}(\boldsymbol{\theta})} = \frac{\int \boldsymbol{\varphi_E}\,\boldsymbol{E}\,\boldsymbol{e}^{-(\mu_{\mathrm{Al}}(\boldsymbol{E})\cdot x_{\mathrm{Al}})}\left(\frac{\mu_{\mathrm{tr}}(\boldsymbol{E})}{\boldsymbol{\rho}}\right)_{\mathrm{air}}\mathrm{d}\boldsymbol{E}}{\int \boldsymbol{\varphi_E}\,\boldsymbol{E}\left(\frac{\mu_{\mathrm{tr}}(\boldsymbol{E})}{\boldsymbol{\rho}}\right)_{\mathrm{air}}\mathrm{d}\boldsymbol{E}}\,,$$

   with $\mu_{\mathrm{Al}}(E)$ being the energy-dependent linear attenuation coefficient of the aluminium, φ_E the spectrum calculated by the "SpekCalc" program and $\left(\frac{\mu_{\mathrm{tr}}(\boldsymbol{E})}{\boldsymbol{\rho}}\right)_{\mathrm{air}}$ the mass-energy transfer coefficient for photons of the energy E in air with the density $\boldsymbol{\rho}$.

3. The thickness x_{Al} was varied until the calculated ratios of the air kerma profiles agreed with the measured ratios for each fan angle θ. The obtained thickness x_{Al} is the aluminium-equivalent thickness of the bow-tie filters.

Figure 3 shows the aluminium-equivalent bow-tie filters.

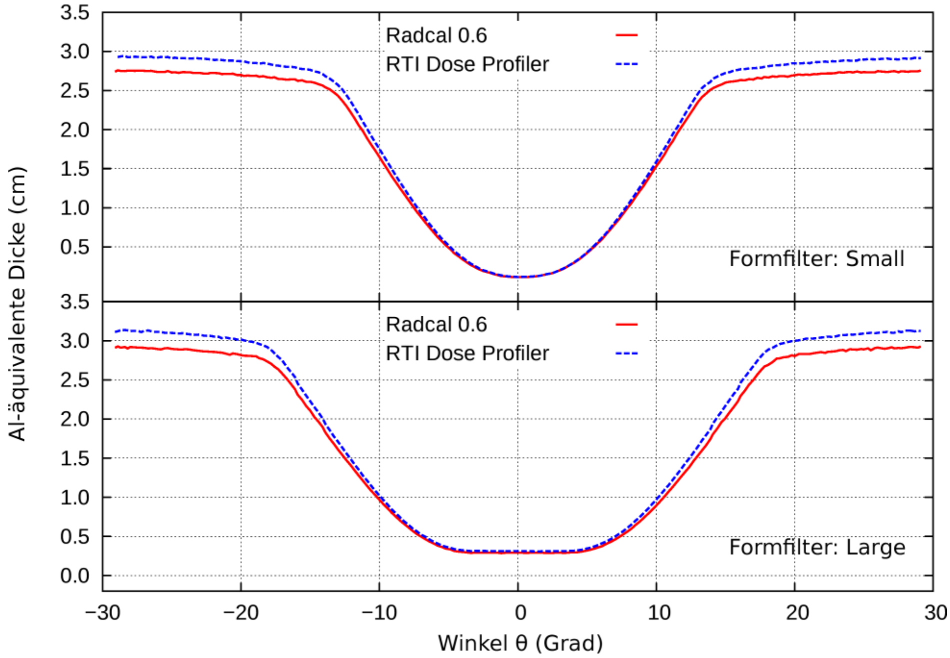

Fig. 3: The aluminium-equivalent thicknesses of the small (top) and of the large (bottom) bow-tie filter obtained using the ionization chamber (red, solid line) and the solid detector (blue, dashed line).

The procedure developed in this work allowed the energy dependence of the response of the solid detector to be corrected. This correction leads to an agreement of the aluminium-equivalent thicknesses which were obtained from the measurements by the two detectors, see Figure 4.

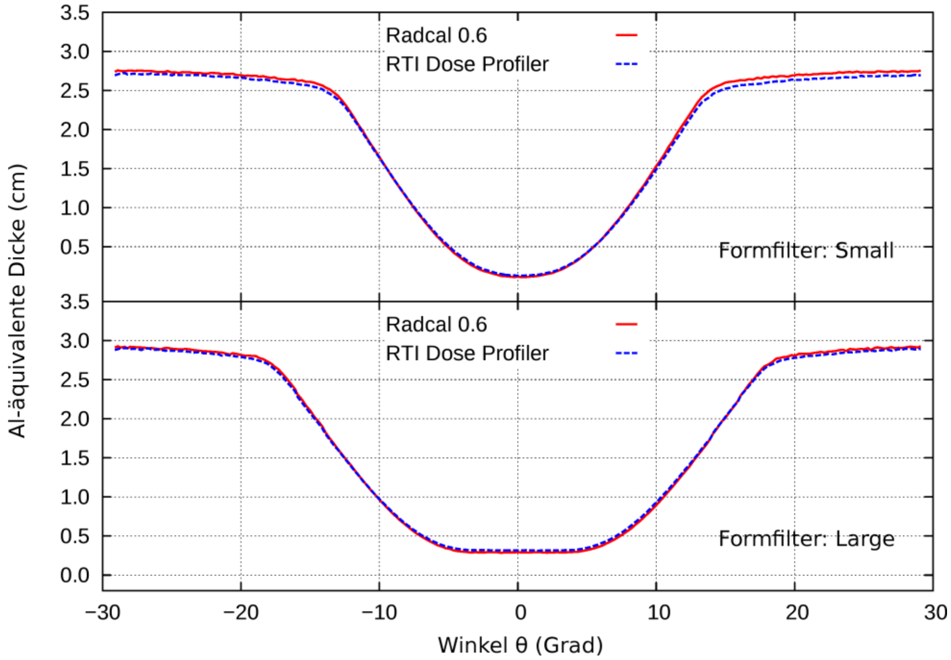

Fig. 4: The aluminium-equivalent thicknesses of the small (top) and of the large (bottom) bow-tie filter obtained by the use of the ionization chamber (red, solid line) and when the solid detector (blue, dashed line). The energy dependence of the air kerma response of the solid detector has been corrected.

References:

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