Mismatch between dosimeter calibration and clinically relevant X-ray spectra and resulting consequences

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Purpose:

Diagnostic dosimeters are important to determine the quality of X-ray devices or doses delivered to patients. Formerly measurements were performed with ionization chambers, while nowadays X-ray multimeters with solid-state detectors (XMMs) are commonly used. In opposite to ionization chambers, XMMs show a prominent energy dependence. Manufacturers address this challenge with device specific calibration procedures, based on X-ray spectra. IEC 61674 [1] specifies requirements for minimum rated ranges (table 1), while the characteristics of the spectra referenced in IEC 61674 are given in IEC 61267 [2] (table 2 for selected quantities).

Due to continuous development in the clinical sector the spectral range as specified in IEC 61674 no longer reflects the clinically available ranges. Within the frame of the EU funded project TraMeXI (traceability in medical X-ray imaging dosimetry) spectral ranges provided by X-ray devices currently in use are determined, enabling a scientifically funded update of IEC standards concerned and thus reliable measurements of doses and further quantities for the use by medical physicists and technical service and the sake of patients.

Influence quantity	Minimum rated range	Reference conditions	Limits of variation
Conventional diagnostic Unattenuated beam	50 kV - 150 kV RQR3 – RQR10 x IEC 61267	70 kV RQR5 x IEC 61267	5 %
Conventional diagnostic Attenuated beam	50 kV – 150 kV RQA3 – RQA10 x IEC 61267	70 kV RQA5 x IEC 61267	
Mammography Unattenuated beam	25 kV – 35 kV Different anode / filter combinations	28 kV	
Mammography Attenuated beam	25 kV – 35 kV Different anode / filter combinations + 2 mmAl filter	28 kV	
Computed tomography	100 kV – 150 kV RQR8 – RQR10 x IEC 61267	120 kV RQT x IEC 61267	
	100 kV – 150 kV RQT8 – RGT10 x IEC 61267		
	100 kV – 120 kV RQA8 – RQA9 x IEC 61267		
Copper-filtered beams	50 kV – 100 kV RQC3 – RQC8 x IEC61267	RQC5	

Table 1: radiation qualities as required for calibration of diagnostic dosimeters

Materials and Methods:

Within a European wide survey with 52 participating sites, information on the spectral combinations (voltage, filtration) used in clinical practice in general radiology, fluoroscopy and interventions, dentistry, mammography and computed tomography (CT) were collected. In addition technical capabilities of medically used X-ray devices was determined in contact with major medical device companies. Results from the survey are presented for fluoroscopy and interventional X-ray units as figure 1.

Combining input from the clinical survey and manufacturer contacts , clinically relevant and physical representative radiation qualities (CPRQs) were determined. X-ray spectra of CPRQs and corresponding half value layer (HVL) were calculated using the program SpekPy V2.0 [3]. Results for simulations of interventional units and CT units are displayed as figures 2 -3.

HVL of CPRQs were set in relation to currently existing requirements from IEC 61674 and an extension of currently existing reference spectra was recommended, to overcome the gap between clinical reality and currently specified minimum rated ranges for dosimeters. Recommendations for copper filtered units are listed as table 3.

IEC 61267 code	Tube voltage / kV	Total filtration / mmAl	1st HVL / mmAl
RQR3	50	2.46	1.77
RQR4	60	2.68	2.19
RQR5	70	2.83	2.57
RQR6	80	2.99	3.01
RQR7	90	3.18	3.48
RQR8	100	3.36	3.96
RQR9	120	3.73	5.00
RQR10	150	4.38	6.55
RQC3	50	2,46 mmAl + 0,5 mmCu	4,42
RQC5	70	2,83 mmAl + 1,5 mmCu	8,46
RQC8	100	3,36 mmAl + 2mmCu	11,59

Table 2: selection of specifications of radiation qualities to be used for calibration of diagnostic dosimeters

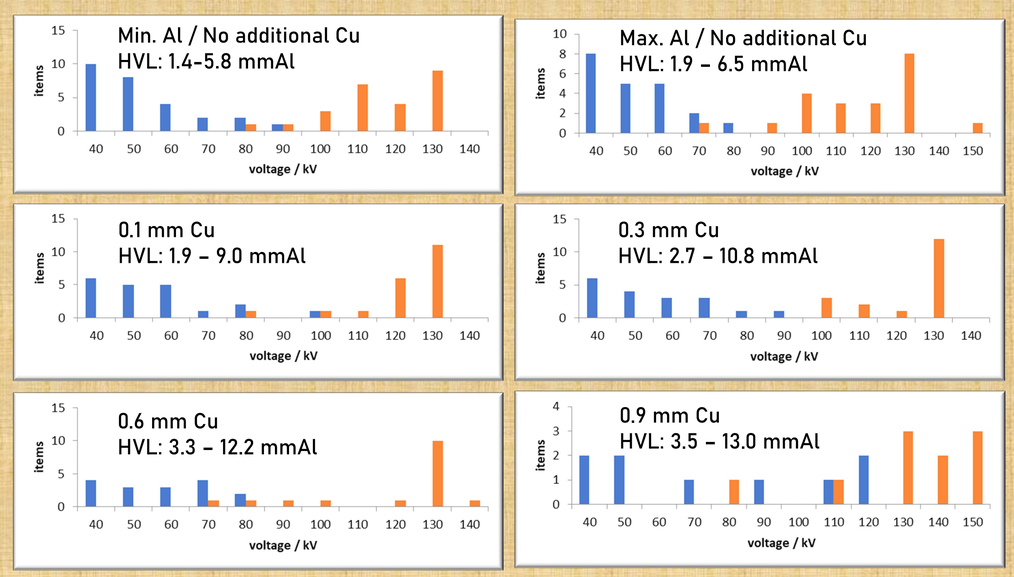

Figure 1: result from the clinical survey - distribution of minimum (blue) and maximum (orange) voltages as used in clinics for differently strong filtered radiation for fluoroscopy and interventional X-ray units. The filtration of (Al)uminum and copper (Cu) as well as corresponding range of HVL values are indicated.

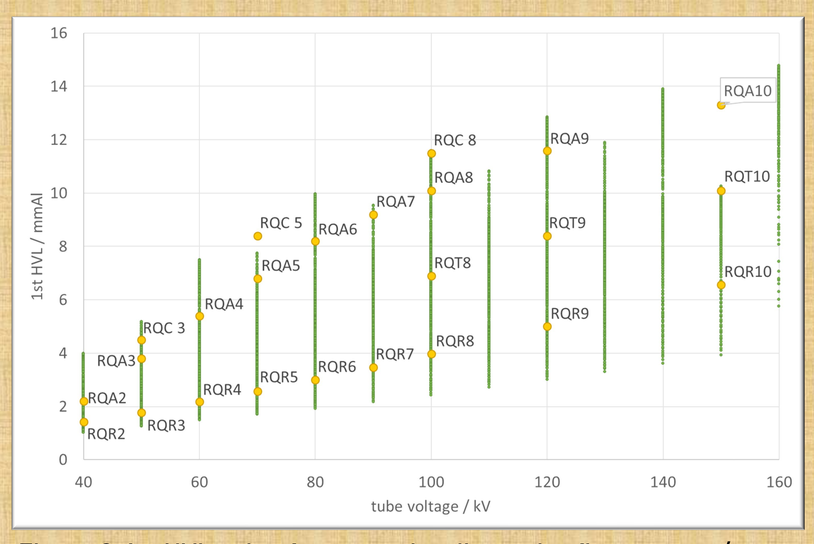

Figure 2: 1st HVL value for general radiography, fluoroscopy / interventional and dental units resulting from differently strong filtration and anode angle in dependence of X-ray tube voltages up to 160 kV (green marks). Reference spectra as specified in IEC 61267 are indicated (yellow).

Conclusions:

Technical feasible and clinically used combinations of X-ray tube voltage and total filtration were assessed and corresponding first HVL calculated.

Resulting HVL were compared to calibration spectra currently specified in corresponding IEC standard.

HVL from clinically relevant spectra clearly outperform the range from spectra specified in IEC 61674.

An extended set of reference X-ray spectra has been published to overcome the existing gap. Realization will be discussed with corresponding IEC committee.

Results:

Figure 1 shows minimum and maximum voltages for spectra filtered from zero to 0.9 mmAl as responded within the clinical survey. The validity for each single response cannot be proven. In general, however, the wide voltage range and the relatively high number of institutions using up to 0.9 mmCu filtered radiation is obvious. Such hard filtered spectra not have been considered at the time when IEC 61674, currently in use, was established. For CT during last years units with Sn filtered spectra came to the market. Such hard filtered spectra, even when beneficial for patients, not have been estimated in former times. For Mammography things are even worse. Here, vendors use in total at least 10 different anode-filter-combinations, challenging dosimeter companies.

Figure 2-3 show the HVL of possible spectra, resulting from tube voltage, anode angle and filtration combinations of X-ray systems currently on the market for units from general radiography, fluoroscopy / interventions and dental applications (Figure 2) and CT units (Figure 3). It is obvious that the possible HVL at different voltages clearly outperform the range of reference spectra currently provided by metrological institutes and calibration services. In the areas that lay outside the range framed by the IEC spectra, behaviour of dosimeters is no longer guaranteed. This becomes prominent for the higher HVL values at 60 kV, 80 kV and 120 kV in figure 2 as well as for voltages of 125 kV and higher in figure 3 as e.g. used for dual energy imaging. However, even within the guarded HVL ranges there exist few step stones only, making the interpolation in between challenging.

Because of the obvious necessity, an extended range of calibration spectra has to be installed. In order to minimize effort recommendations are based on already existing spectra. The recommendation for copper filtered spectra is shown as table 3. Extra filters of 0.1 mmCu, 0.3 mmCu and 0.9 mmCu are needed, only, to fill existing gaps and extend the range of spectra as currently observed in HPRQs. Likewise recommendations for CT and Mammography will be published and discussed with the corresponding IEC committee.

Realization based on	Tube voltage / kV	Typical total filtration / mmAl	0.1 mmCu	0.2 mmCu	0.25 mmCu	0.3 mmCu	0.5 mmCu	0.9 mmCu	1.5 mmCu	2.0 mmCu
RQR3	50	2.46	**New**			**New**	RQC3			
RQR4	60	2.68						**New**		
RQR5	70	2.83	**New**			**New**		**New**	RQC5	
RQR8	100	3.36	**New**	RQT8		**New**		**New**		RQC8
RQR9	120	3.37	**New**		RQT9	**New**		**New**		
RQR10	150	4.38	**New**			RQT10		**New**		

Table 3: table showing the currently established step stones to cover the voltag and HVL range for general radiography, fluoroscopy and interventional units (copper filtered radiation) and recommended new reference radiation qualities to increase teh HVL

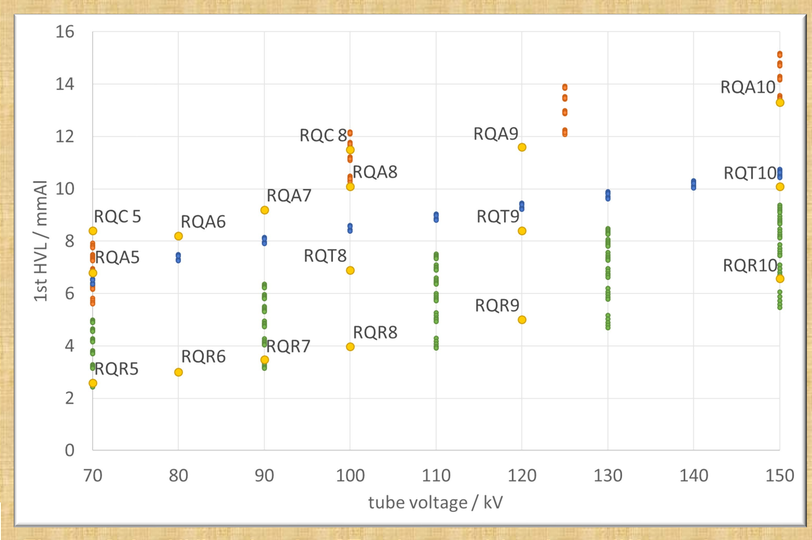

Figure 2: 1st HVL value for CT units resulting from differently strong filtration and anode angle in dependence of X-ray tube voltages up to 150 kV. Conventional filtration is shown as green symbols, gold in blue and tin filtration as orange symbols. Reference spectra as specified in IEC 61267 are indicated (yellow).

Literature:

[1] IEC 61674:2012, *Medical electrical equipment – Dosimeters with ionization chambers and / or semiconductor detectors as used in X-ray diagnostic imaging*

[2] IEC 61267:2005; *Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics*

[3] Poludniowski et. al., *Technical Note: SpekPy v2.0 – a software toolkit for modelling x-ray tube spectra*, Med. Phys. 2021 Jul; 48(7):3630-3637

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