Establishing Standard X-ray Narrow-beam Radiation Qualities in the Secondary Standard Dosimetry Laboratory

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***Abstract*—Prior to performing calibrations in the Secondary Standard Dosimetry Laboratory (SSDL), standard radiation qualities must be determined in order to accurately assess the absorbed dose of occupationally exposed personnel and to evaluate the performance of radiation measurement instruments. Due to the energy dependence of the calibration factor and the air kerma to the personal dose equivalent conversion factor, it is of great importance to properly establish standard radiation qualities. Radiation qualities can be characterized by determining their photon energy distributions, or by using the X-ray tube voltage and the first and second half-value layers. In this paper, the half-value layers were determined by varying the thicknesses of the additional filtration absorbers. The calculated values show a deviation from the ISO standard values not greater than 6%.**

***Index Terms*—Half-value layer, Radiation protection, X-ray**

I. INTRODUCTION

Medical X-ray photon fields in the energy range of 10-150 keV are used in the field of diagnostic radiology. Apart from the standard RQR radiation quality series, used for primary X-ray beam measurements, and the RQT radiation qualities, used for computed tomography imaging (defined in [1]), the narrow-beam series (N-series) radiation qualities (defined in [2]) are of great importance for the radiation protection aspects of diagnostic radiology. Radiation qualities are defined by their photon energy distributions. Determining the energy distribution of the photons usually requires complicated spectrometry procedures, which is why it is more convenient to define radiation qualities by using the X-ray tube voltage and the first and second half-value layer (HVL) [3]. Dosimeters used in radiation protection have a pronounced energy dependence of the response. Even though the energy dependence is usually determined during the type testing of the dosimeters, it is desirable to perform the calibrations in certain radiation qualities, which mostly resemble the conditions the dosimeter will be used in. Narrow-beam radiation qualities have a narrow energy spectrum, which is why these radiation qualities are convenient for energy dependence determination. In Fig. 1 the relative energy response of two electronic personal dosimeters (EPDs) is displayed [4]. Dosimeter A is based on a silicon (Si) diode detector, while dosimeter B is based on a Geiger–Müller (G-M) tube. The greatest deviations of the energy response from the reference value (measured for the S-Cs radiation quality) for the two displayed dosimeters have been calculated, where a maximum underresponse of -25% has been recorded for dosimeter A, and a maximum overresponse of +25% for dosimeter B.

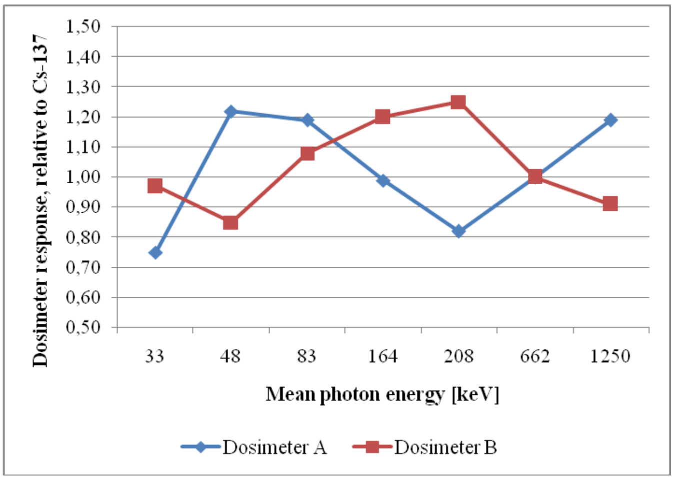

Fig. 1. Relative dosimeter responses of two types of EPDs.

Because of such fluctuations in dosimeter responses due to photon energy variations, it is vital to ensure that standard radiation qualities are established properly by measuring the HVL. The purpose of this paper is to describe the procedure of establishing the N-series radiation

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qualities in order to prevent any systematic errors that may occur during the calibrations because of the energy dependence of the calibration factor and air kerma to personal dose equivalent conversion factor [5]. The N-series radiation qualities were established by determining the first HVL for these radiation qualities and the first HVL when no additional filtration is used apart from the inherent filtration. The results were compared to the corresponding standard.

II. Materials and Methods

The HVL measurements were performed on a X80-225kV-E X-ray generator (manufactured by Hopewell Designs) in the Secondary Standard Dosimetry Laboratory (SSDL) of the Department of Radiation and Environmental Protection, which is a part of the Vinča Institute of Nuclear Sciences. The amount of the generated charge by the X-ray photons was measured with a 3.00 cm^3 Exradin Magna A650 plane-parallel ionization chamber with a PTW Unidos electrometer. The distance between the reference point of the ionization chamber and the focal point of the X-ray tube was set at 100 cm. Copper absorbers with thicknesses ranging from 0.02 to 4.98 mm were set equidistant from the ionization chamber and the X-ray tube focus (Fig. 2).

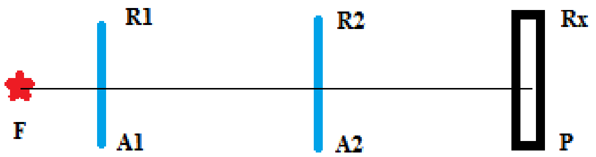

Fig. 2. HVL measurement setup: F represents the focal point of the X-ray tube; A1 is the position of the aperture which limits the field size after the beam passes through the inherent and additional filtration for the selected radiation quality; A2 is the position of the aperture where the additional filtration for the purpose of HVL measurements has been placed; P is the point of test where the ionization chamber was placed. R1 and R2 represent the field diameters for the A1 and A2 apertures, and Rx is the diameter of the field at the point of test.

The experimental setup is shown in Fig. 3. The apertures limit the beam area, and have an insignificant scatter contribution to the measurements. The beam area is large enough to ensure that the ionization chamber is completely irradiated [6]. During the HVL measurements of the narrow-beam radiation qualities, the inherent filtration of the X-ray tube was set to 4.00 mm of aluminum. In the experimental part of the paper seven narrow-beam radiation qualities, defined in [2], were used, and their characteristics are shown in Table 1. The X-ray tube voltage ranged from 40 kV (for the N-40 radiation quality) to 200 kV (for the N-200 radiation quality), while the tube current was set to 15 mA. In this paper only the first HVLs were determined, since the homogeneity coefficients for the narrow-beam radiation qualities are close to one. This is not the case for the RQR radiation qualities where the first and second HVLs differ from each other significantly [1].

Fig. 3. Experimental setup for the HVL measurements.

Table I
Characteristics of the standard radiation qualities from the narrow spectrum series [2].

Radiation quality	Additional filtration [mm]			First HVL [mm Cu]	Second HVL [mm Cu]
	Cu	Sn	Pb		
N-40	0.21	/	/	0.084	0.091
N-60	0.60	/	/	0.24	0.26
N-80	2.00	/	/	0.58	0.62
N-100	5.00	/	/	1.11	1.17
N-120	5.00	1.00	/	1.71	1.77
N-150	/	2.50	/	2.36	2.47
N-200	2.00	3.00	1.00	3.99	4.05

The collected charge was measured for each radiation quality and each absorber thickness 10 times. Each measurement was performed for the duration of 60 s. The thicknesses of the additional copper filtration for each radiation quality are shown in Table 2.

Table II
Copper absorber thicknesses used for the HVL measurements for different narrow-beam radiation qualities.

Radiation quality	Cu absorber thickness [mm]				
N-40	0.02	0.05	0.10	0.14	0.19
N-60	0.05	0.10	0.19	0.24	0.28
N-80	0.19	0.38	0.58	0.67	0.72
N-100	0.48	0.98	1.17	1.36	1.51
N-120	0.48	0.98	1.36	1.65	1.93
N-150	0.98	1.93	2.41	2.91	3.39
N-200	1.93	2.91	3.87	4.35	4.98

For the inherent filtration HVL measurements, the experimental procedure was the same, with an exception that aluminum absorbers of various thicknesses ranging from 0.11 to 5.13 mm were used, instead of copper ones. The X-ray tube voltage was set to 60 kV and the tube current was set to 15 mA.

III. Results and Discussion

The measured values of the charge were averaged for each radiation quality and each copper filtration thickness. The attenuation of the beam was determined by comparing the collected charge values for each copper absorber thickness with the collected charge value measured with no additional filtration. The natural logarithm of the collected charge ratios for each copper absorber thickness and each radiation quality were calculated, according to the exponential law of attenuation (Eq. 1). The measured average values of the collected charge and the logarithm of the collected charge ratios are listed in Table 3 and are graphically represented on Figs. 4-10. Copper absorber thickness (*d*) is given in [mm], collected charge Q_{sr} in [pC/min], and *A* represents the natural logarithm of the charge ratios, given by Eq. 1.

$$A = \ln(Q_{sr} / Q_{sr0}) \tag{1}$$

TABLE III
THE MEASURED VALUES OF THE COLLECTED CHARGE AND LOGARITHM OF THE CHARGE RATIOS FOR EACH RADIATION QUALITY AND EACH COPPER ABSORBER THICKNESS.

N-40	d	0.00	0.02	0.05	0.10	0.14	0.19
	Qsr	121	102	79	55	41	28
	A	0	0.17	0.42	0.78	1.08	1.44
N-60	d	0.00	0.05	0.10	0.19	0.24	0.28
	Qsr	217	185	162	123	107	96
	A	0	0.16	0.29	0.57	0.71	0.81
N-80	d	0.00	0.19	0.38	0.58	0.67	0.72
	Qsr	107	86	69	55	50	47
	A	0	0.23	0.44	0.66	0.76	0.82
N-100	d	0.00	0.48	0.98	1.17	1.36	1.51
	Qsr	55	41	30	27	24	22
	A	0	0.29	0.60	0.71	0.83	0.92
N-120	d	0.00	0.48	0.98	1.36	1.65	1.93
	Qsr	62	51	42	36	32	29
	A	0	0.19	0.39	0.53	0.65	0.76
N-150	d	0.00	0.98	1.93	2.41	2.91	3.39
	Qsr	452	339	259	226	196	172
	A	0	0.29	0.56	0.69	0.84	0.96
N-200	d	0.00	1.93	2.93	3.87	4.35	4.98
	Qsr	176	127	108	92	85	77
	A	0	0.33	0.49	0.65	0.73	0.83

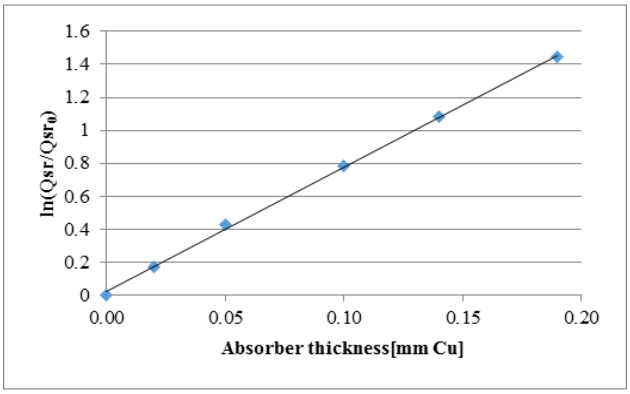

Fig. 4. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-40 radiation quality.

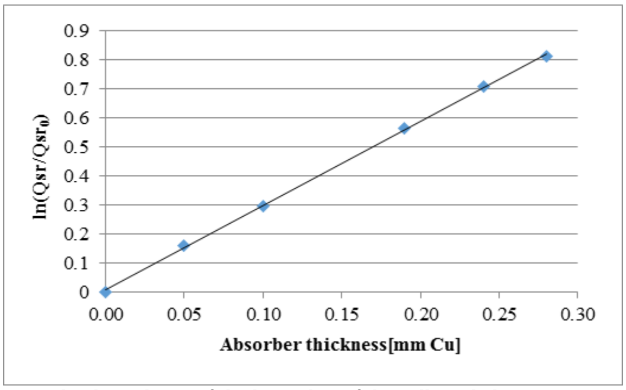

Fig. 5. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-60 radiation quality.

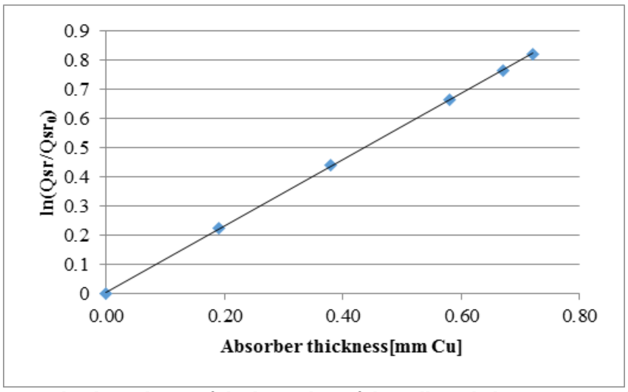

Fig. 6. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-80 radiation quality.

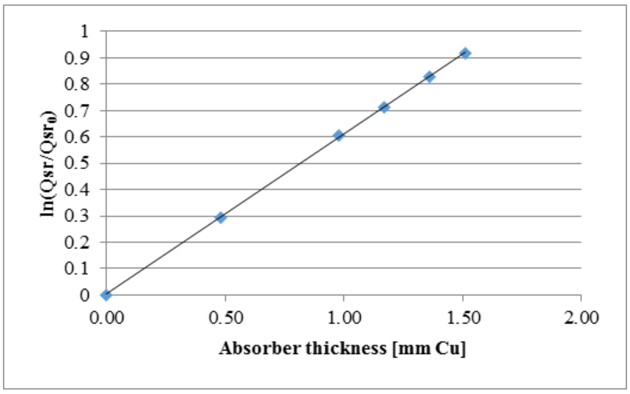

Fig. 7. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-100 radiation quality.

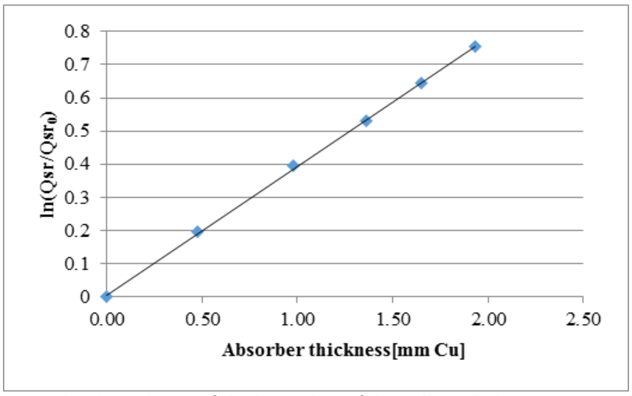

Fig. 8. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-120 radiation quality.

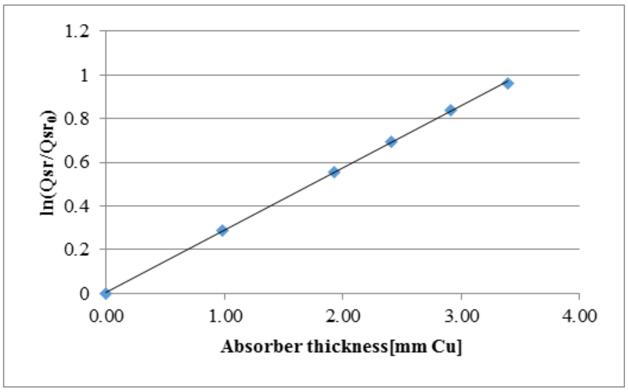

Fig. 9. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-150 radiation quality.

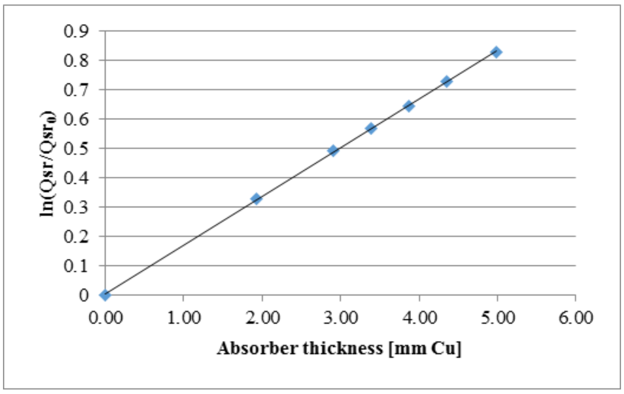

Fig. 10. The dependence of the logarithm of the collected charge ratio on the thickness of the copper absorber for the N-200 radiation quality.

The HVLs have been determined by linear curve fitting of the calculated data, and by using the straight line equation in Microsoft Office Excel. The calculated HVLs are listed in Table 4 along with the standard HVL values [2]. The deviations of the calculated HVLs from the standard values are displayed on Fig. 11.

TABLE IV
COMPARISON OF THE CALCULATED HVLS WITH THE STANDARD VALUES.

Radiation quality	Calculated HVL [mm Cu]	HVL given by [2] [mm Cu]
N-40	0.089	0.084
N-60	0.236	0.24
N-80	0.61	0.58
N-100	1.14	1.11
N-120	1.77	1.71
N-150	2.42	2.36
N-200	4.16	3.99

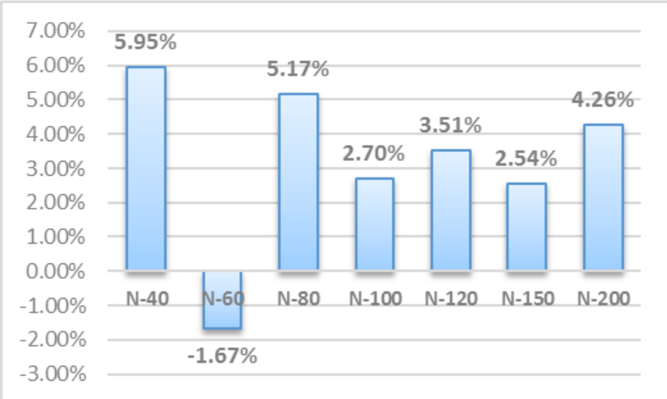

Fig. 11. The deviation of the calculated HVLs from the reference values given by [2]. According to the standard, the measured HVLs should agree within ±5% from the reference values. Otherwise measurements should be repeated until the criterion is met, by adjusting the X-ray tube voltage.

The inherent filtration HVL was determined by the same procedure. The calculated HVL was 2.64 mm of Al, while the reference standard value was 2.75 mm of Al, according to [2]. The deviation of the calculated HVL from the standard value is -4.00%.

IV. CONCLUSION

In this paper the procedure of establishing standard narrow-beam radiation qualities, which are used in radiation protection, has been performed. This was done by determining the HVLs for the X-ray photons with the energy up to 200 keV. The measurements were performed by placing copper or aluminum absorbers of various thicknesses (depending on whether the N-series radiation qualities or the X-ray generator inherent filtration HVL values were calculated) equidistantly from the focal point of the X-ray tube and the plane-parallel ionization chamber. The resulting HVLs deviate from the ISO standard values the most for the N-40 radiation quality (5.95%), and the least for the N-60 radiation quality (-1.67%), while the deviation for the inherent filtration HVL measurements was -4.00%. According to the standard [2], if the deviation from the standard values is greater than ±5%, measurements should be repeated until the criterion is met, while adjusting the X-ray tube voltage. Otherwise this deviation should be taken into account by expanding the measurement uncertainty budget.

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