Establishing the RQR radiation qualities in the Secondary Standard Dosimetry Laboratory

Nikola Kržanović, Miloš Živanović, Olivera Ciraj-Bjelac, Predrag Božović, Andrea Kojić

***Abstract*—Quality assurance in the area of diagnostic radiology is performed by examining X-ray output parameters under medical exposure irradiation conditions using calibrated dosimetry equipment. The diagnostic radiology dosimeters are calibrated in reference radiation fields established according to IEC 61267 international standard. In practice, radiation qualities are defined by the X-ray tube voltage and the half-value layer and homogeneity coefficient. Comparison of these parameters with the recommendations of the standard can be used for incident photon spectrum characterization and modification by improving the added filtration for each radiation quality, thus acquiring the desired half-value layer for the given X-ray tube voltage. For most of the diagnostic radiology radiation qualities available at the Secondary Standard Dosimetry Laboratory a deviation of the first half-value layer less than ±3% was achieved, with an exception of one radiation quality where a correction would be required.**

***Index Terms*—Diagnostic radiology; Half-value layer; Homogeneity coefficient, X-ray.**

I. Introduction

THE medical imaging procedures in diagnostic radiology utilize radiation fields consisting of a wide range of different X-ray photon energies. In order to improve the quality of diagnostic procedures in hospitals, periodic quality assurance (QA) testing of X-ray generators is performed. The dosimetry equipment used for these measurements should be calibrated in a Standard Dosimetry Laboratory, ensuring the traceability to the primary standard for kerma free-in-air. For the dosimetry equipment calibration purposes, radiation fields with specific parameters and known spectra are defined as radiation qualities. Full characterization of the radiation qualities can be performed by measuring the photon fluence spectra. Due to the complexity of the X-ray spectrometry measurements, in practice these radiation qualities are defined with X-ray tube voltage and the half-value layer (HVL) [1]. For the equipment calibration in the direct beam in diagnostic radiology, RQR (Radiation Qualities in Radiation beams emerging from the X-ray source assembly) series radiation qualities are used, as defined in IEC 61267 [1] [2].

By establishing the radiation qualities considering the recommendations of the international standard, calibrations of the dosimetry equipment can be performed in radiation fields which are closely related to the radiation fields present under the medical exposure conditions. For specific diagnostic radiology applications such as mammography and computerized tomography, IEC 61267 defined radiation qualities RQR-M and RQT are used, respectively [2].

On the other hand, non-standard radiation qualities might be more appropriate for specific fluoroscopy applications, essentially those in interventional radiology and interventional cardiology procedures. Therefore, in order to improve the calibration procedures of the QA dosimeters, under the framework of the VERIDIC project, a series of non-standard radiation qualities, which closely describe medical exposure radiation fields in interventional radiology and interventional cardiology procedures, has been developed [3].

Due to the diagnostic radiation quality beam hardening it is not sufficient to describe the beam by solely determining the first HVL, therefore the determination of the first and second HVL is required. Considering the exponential law of attenuation of the primary beam, the first and second HVL are defined as:

$$HVL_1 = d_{1/2} = \frac{\ln 2}{\mu} \tag{1}$$

$$HVL_2 = d_{1/4} - HVL_1 = \frac{\ln 4}{\mu} - HVL_1 \tag{2}$$

where μ is the linear attenuation coefficient of the absorber material, $d_{1/2}$ and $d_{1/4}$ are the absorber thicknesses which attenuate the primary beam intensity (i.e. air kerma rate) to half and to quarter of the initial value, respectively. By comparing the values of the first and second HVL the homogeneity coefficient h is defined [1].

Nikola Kržanović is with the Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, University of Belgrade, 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (krzanovic@vin.bg.ac.rs)

Miloš Živanović is with the Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, University of Belgrade, 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (milosz@vin.bg.ac.rs)

Olivera Ciraj-Bjelac is with the School of Electrical Engineering, University of Belgrade, 73 Bulevar Kralja Aleksandra, 11020 Belgrade, Serbia; Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, University of Belgrade, 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (ociraj@vin.bg.ac.rs)

Predrag Božović is with the School of Electrical Engineering, University of Belgrade, 73 Bulevar Kralja Aleksandra, 11020 Belgrade, Serbia; Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, University of Belgrade, 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (bozovic@vin.bg.ac.rs)

Andrea Kojić is with the Faculty of Physics, University of Belgrade, 12 Studentski Trg, 11001 Belgrade, Serbia; Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, Department of Radiation and Environmental Protection, University of Belgrade, 12-14 Mike Petrovića Alasa, 11351 Vinča, Belgrade, Serbia (andrea.kojic@vin.bg.ac.rs)

$$h = \frac{HVL_1}{HVL_2} \quad (3)$$

In the previous research regarding characterization of the diagnostic radiology X-ray fields, the first and second HVL and the homogeneity coefficient were determined only for a part of the RQR series, due to the available radiation qualities at the SSDL at the time [4]. Following the previous characterization procedure the old X-ray generator Phillips MG320 has been replaced by the current Hopewell Designs X80-225 kV-E generator, requiring new characterization procedure of the diagnostic radiology X-ray fields.

In this paper values of the first and second HVL are determined in order to establish the RQR series in the Vinca Institute of Nuclear Sciences Secondary Standard Dosimetry Laboratory (SSDL).

II. Materials and Methods

The RQR radiation quality series is used for the calibration of dosimetry equipment which would be used under clinical conditions that correspond to various radiography and fluoroscopy procedures. These radiation qualities are based on X-ray tube voltages in the range from 40 kV up to 150 kV. In Table 1, the properties of RQR radiation qualities in terms of X-ray tube voltage, first HVL and homogeneity coefficient are displayed [1].

TABLE I
RADIATION BEAM EMERGING FROM X-RAY ASSEMBLY (RQR) RADIATION QUALITY PROPERTIES USED FOR CALIBRATION OF THE QA DOSIMETERS [1].

Radiation quality	*U* [kV]	1st HVL [mm Al]	*h*
RQR2	40	1.42	0.81
RQR3	50	1.78	0.76
RQR4	60	2.19	0.74
RQR5	70	2.58	0.71
RQR6	80	3.01	0.69
RQR7	90	3.48	0.68
RQR8	100	3.97	0.68
RQR9	120	5.00	0.68
RQR10	150	6.57	0.72

The diagnostic radiology beams were characterized for the Hopewell Designs X80-225 kV-E X-ray generator which operates in the continuous mode. The HVL measurements were performed by using the 3.6 cm^3 secondary standard spherical ionization chamber Exradin A3 (Standard Imaging) with the UNIDOS Webline (PTW) electrometer. The ionization chamber was calibrated together with the electrometer in the IAEA Dosimetry Laboratory, establishing traceability to the primary standard for all the RQR series radiation qualities. The reference radiation quality in the RQR series is the RQR5 radiation quality. The standard ionization chamber has negligible energy response dependence over a wide energy range, not requiring correction factors for this influence quantity.

The ionization chamber is positioned at the distance specific for the calibration of the dosimetry equipment, being 100 cm. Owing to the fact that the fluctuations in the output of the X-ray generator lead to variations in the measured air kerma rate values, a correction for these variations is needed. In order to correct the X-ray output variation, a plane-parallel transmission ionization chamber is positioned after the filtration of the primary radiation beam. The PTW 34014 ionization chamber with the PTW UNIDOS electrometer has been used for the charge measurements during the air kerma rate measurements with the reference standard.

The additional filtration absorbers are placed equidistantly from the ionization chamber and the monitor chamber in order to minimize the effects of scattered radiation during the HVL measurements. The aperture at the position of the aluminum absorbers has a diameter of 3.8 cm, leading to the field diameter at the point of test of 5.8 cm. The distances between the ionization chamber and the absorber and between the absorber and the monitor chamber were 34 cm, which is greater than five times the field diameter at the point of test. By ensuring that this condition is fulfilled, the production of scattered radiation from the aluminum absorber is negligible, and the contribution of this radiation to the measured signal of the ionization chamber and the monitor chamber is minimized.

The measurement set-up for the HVL measurements is displayed in Fig. 1, while the image in which the ionization chamber, aperture where additional filtration is placed and the X-ray generator are displayed in Fig. 2.

The first and second HVL were estimated by successively increasing the additional filtration aluminum absorber thickness, and measuring the air kerma rate. All of the air kerma values were compared to the initial air kerma rate value measured when no additional filtration has been added. In order to determine the attenuation curves for all of the radiation qualities, aluminum absorber thicknesses ranging from 0.7 mm to 20.0 mm were used. Since the air density represents an important influence quantity for the air kerma measurements, all of the standard and monitor ionization chamber measurements were corrected for the ambient conditions (the effects of ambient temperature and pressure).

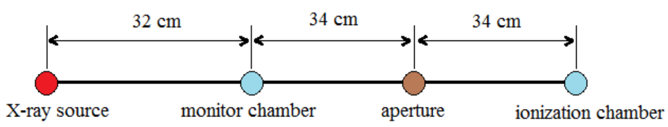

Fig. 1. Measurement set-up for the HVL measurements. The aperture where the additional aluminum filtration is added is positioned equidistantly between the ionization chamber and the monitor chamber, due to the minimization of the scattered radiation contribution. The ionization chamber is placed on the calibration distance of 100 cm from the X-ray source.

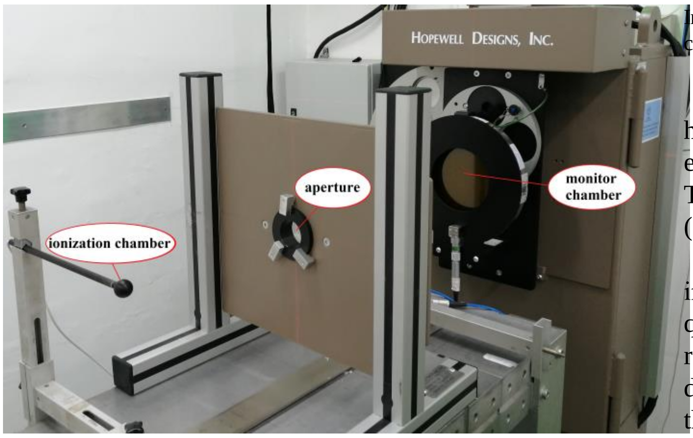

Fig. 2. HVL measurement set-up with indicated ionization chamber, monitor chamber and the aperture where the additional aluminum filtration of various thicknesses was positioned.

III. Results and Discussion

For all the RQR radiation qualities the attenuation curve (according to the exponential attenuation law in the absorber material) has been recorded. The aluminum filter thicknesses were successively increased, where the filter thickness increase steps near the absorber thicknesses that correspond to the targeted HVL values given in the standard [1] [2] were smaller.

Due to the beam hardening the HVL cannot be estimated by performing the attenuation curve fitting over the whole dataset, therefore the first and second HVL were determined by performing interpolation of the data for the absorber thicknesses near the expected HVL values. In Figure 3 the recorded attenuation curve for the RQR5 radiation quality is displayed. All of the air kerma rate values were corrected for the influence of the X-ray generator output variations and normalized to the values measured when no additional filtration was added at the position of the aperture, for each radiation quality separately.

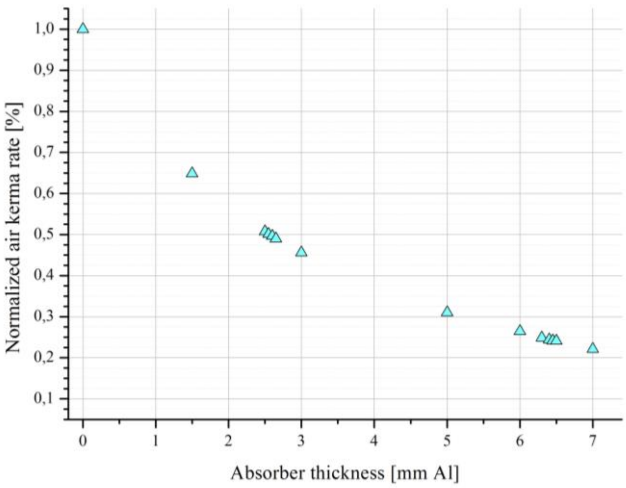

Fig. 3. Attenuation curve recorded for the RQR5 radiation quality. Air kerma rate was corrected for the output variation of the X-ray generator and normalized to the value with no added filtration at the aperture position. Increased number of data points was measured for the aluminum thicknesses close to the HVL standard values [1].

The first and second HVL values were estimated, and the homogeneity coefficient has been determined by using the equations 1-3. The obtained HVL values are displayed in Table 2, along with the deviations from the reference values (displayed in Table 1).

Deviation of the measured first HVL from the values given in IEC 61267 [2] is less than ±5% for all the radiation qualities in the RQR series. The lowest deviation from the reference HVL value was determined for the reference diagnostic radiology radiation quality RQR5 (-0.4%), while the largest deviation from the standard was recorded for the RQR9 and RQR10 radiation qualities. Regarding the second HVL and the homogeneity coefficient, the largest deviation from the standard [2] values is observed for the RQR4 radiation quality, while there was no deviation of the homogeneity coefficient determined for the RQR3 and RQR7 radiation qualities.

TABLE II
Estimated first and second HVL values and the homogeneity coefficients for the RQR radiation qualities, and the deviations from the reference values.

Radiation quality	HVL_1	HVL_2	h	$\Delta(d_{1/2})$ [%]	$\Delta(h)$ [%]
RQR2	1.40	1.78	0.79	-1.4	-2.5
RQR3	1.77	2.34	0.76	-0.6	0.0
RQR4	2.17	3.04	0.71	-0.9	-4.1
RQR5	2.57	3.69	0.70	-0.4	-1.4
RQR6	3.06	4.33	0.71	1.7	2.9
RQR7	3.55	5.26	0.68	2.0	0.0
RQR8	4.01	6.08	0.66	1.0	-2.9
RQR9	5.13	7.70	0.67	2.6	-1.5
RQR10	6.85	9.43	0.73	4.3	1.4

Considering the criteria set by the standard [1] [2], the primary beam specifying quantities (X-ray tube voltage and the first HVL) should be adjusted as closely as possible to the values presented in Table 1, in such a way that the ratio of air kerma rate with and without additional filtration at the aperture position is in the range 0.485 - 0.515. If the estimated air kerma ratio for the given HVL lies slightly out of the given range, additional filtration thickness correction may be needed. The maximum deviation for the secondary beam specifying quantity (homogeneity coefficient) is ±0.03 from the values given in Table 1 for each of the radiation qualities.

The measured air kerma rate values for added filtration corresponding to the first HVL, as well as the estimated values of homogeneity coefficient, were in accordance with the standard.

IV. Conclusion

The Secondary Standard Dosimetry Laboratory represents an important element in enforcing the metrology traceability chain, improving the quality of dosimetry measurements in diagnostic radiology by performing adequate calibration procedures in the reference radiation fields established according to the IEC standard. The first and second HVL measurement results would contribute to the eventual corrections of the manufacturer preset X-ray beam filtrations in order to reduce the deviation from the standard HVL and homogeneity coefficient values, ensuring that the X-ray spectra are quantitatively well characterized. Employing characterized X-ray fields for diagnostic radiology improves the calibration and testing procedures of dosimetry equipment designated for the use under medical irradiation conditions. Furthermore, future introduction of new radiation qualities with X-ray tube voltages and filtrations in close correspondence with clinical conditions, and establishing these new radiation qualities in SSDLs would result in improvement of dosimetry equipment accuracy on-site.

Acknowledgment

This research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

References

[1] *Dosimetry in Diagnostic Radiology: An International Code of Practice*, IAEA TRS 457, 2007.

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

[3] O. Ciraj-Bjelac, N. Kržanović, M. Živanović, V. Blideanu, F. De Monte, M. Deleu, A. Feghalli Joelle, A. Gallagher, Ž. Knežević, C. Maccia, F. Malchair, J. Plagnard, M. Sans Merce, G. Simantirakis, J. Dabin, „VERIDIC: Validation and estimation of radiation skin dose in interventional cardiology“, XXX Simpozijum DZZSCG, Divčibare, Srbija, pp. 386-392, 2nd-4th October, 2019.

[4] D. Čekerevac, O. Ciraj-Bjelac, M. Živanović, P. Božović, “Uspostavljanje standardnih kvaliteta snopa u SSDL za primenu u oblsati dijagnostičke radiologije”, XXVI Simpozijum DZZSCG, Tara, Srbija, pp. 229-233, 12th-14th October, 2011.