AN APPROACH FOR THE CALIBRATION OF THE KVP FOR THE X-RAY TUBES

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Abstract

This paper proposes two different methods for the calibration of the applied tube voltage (kVp) for the low and medium energy X-ray. First method is based on studying direct measurements of the emitted X-ray spectrum by Hyper Pure Germanium Detector (HPGD) gamma and X-Ray spectrometer, where the endpoint of the spectra is equal to the kVp of the X-ray tube. The second depends on studying the characteristic X-Ray Fluorescence (XRF) emitted from some studied reference materials such as Tin (Sn), Cadmium (Cd) and Lead (Pb) as a function of applied voltage on the X-ray tube. The XRF was measured by a standard dosimeter composed of ion chamber and electrometer. It was found that each of the proposed methods gave an exact value of the kVp. The endpoint spectrum gives a calibration factor of 1.003. The XRF method gives a calibration factor of 1.015 for IRML X-ray tube. An empirical formula between the X-ray energy and the applied voltage of X-ray tube was obtained. Moreover, the mean energy of the X-ray was obtained as a function of kVp.

Keywords: *X-ray, XRF, Calibration*

Introduction

X-ray has many industrial and medical applications. Quality assurance and quality control should be performed for the X-ray machine before its use [1]. The measured parameters through the quality control are the applied tube voltage (kVp), the output radiation dose, dose rate, exposure time and the current-dose linearity.

The traditional methods for kVp measurements for X-ray are direct measurements of the applied kVp by potential divider or non-invasive methods. Many authors use the direct measurements of the X-ray spectrum of photon spectroscopic methods as the use of Hyper Pure Germanium Detector (HPGD) [2-4]. There are two theories for generating X-rays. The first one is called the *Parking radiation*, due to the collision of accelerated electrons to the target inside the vacuum tube. The second theory is the *Distinctive X-ray* that is generated as a result of excitation of electrons in energy levels close to the nucleus of the atoms. The X-ray spectrum is defined as the energy distribution of the radiation produced in X-ray exposure. In ideal cases, the endpoint of the spectrum equals the kVp applied on the X-ray generator [5, 6].

The aim of this article is the calibration of the kVp for the Ionizing Radiation Metrology Laboratory (IRML) X-ray tube. The calibration was performed first by the measurement of the direct spectrum by HPGD. As for the second method for calibration, the XRF of some standard materials were used to calibrate the kVp and comparing between the two methods. Moreover, the present work aimed to get an empirical formula for kV-keV from X-ray beam and another formula for mean energy X-ray as a function of HVL in Al and Cu filter.

Experimental work

X-Ray tube machine

In this study, Philips X-ray machine with type MCN 323 metal-ceramic with a double pole and tungsten anode was used as a reference beam [7]. The MG325 Philips X-ray system is highly stabilized constant potential X-ray system that connected to the tube. The High Voltage (HV) is directly measured by means of a potential divider built in the HV generator. The system can be used for calibration of dosimeters and ionization chambers which are used for irradiation measurements and radiation protection. The heart of the control unit MGC 40 is a microprocessor which provides maximum, of easy and safe operation. A permanent monitoring of set values and actual ones for kV and mA ensures very high stability of the data. The HV and tube current adjustment (four-digit LED display) are 15 - 320 kV and 0 - 22.5 mA, respectively [8]. The setting up for X-ray machine was performed according to IAEA report [9].

X-Ray spectrum measurements

The spectrum of X-ray was measured by 3x3 ORTEC HPGD connected to the Nomad multichannel analyzer. Calibration of HPGD was performed using two characteristic X-ray of Cs^{137} K_{α} and K_{β} with energies of 30.91 and 34.98 keV, respectively. The X-ray emission for some standard reference material such as Sn, Cd and Pb filters of 99.99 % purity was measured.

XRF measurements

The standard X-ray fluorescence emitted from a reference material filter such as Sn, Cd and Pb was measured using the secondary standard dosimetry system of the National Institute of Standards (NIS) – Egypt.

The system is composed of PTW Unidos electrometer and PTW 300013 ionization chamber, the secondary standard calibration system was calibrated at the Bureau International des Poids et Mesre (BIPM) in 2017. The filter was supported with angle 45° of a small field size X-ray beam as shown in Fig. 1.

The emitted X-ray dose was measured as a function of kV. The kVp was slightly increased while the XRF dose was measured. When kVp was ≥ the energy of XRF of the used filter, the XRF dose increased linearly with kVp values.

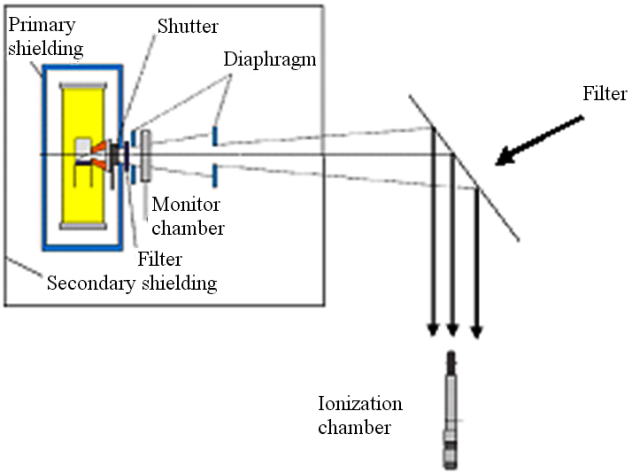


Fig. 1. The setup of the XRF measurements

Results and discussions

Calibration of kVp

Direct spectrum method

In this method, the emitted X-ray beam at a certain kV was directly measured by the HPGD. Fig. 2 shows a typical spectrum of different kV for different X-ray beams of the Consultative Committee of Ionizing Radiation (CCRI) with 25, 50,100,135 and 180 kV [9-11]. From the figure, it can be noticed that the endpoint of the spectrum is equal to the kV of the X-ray tube, as shown in Fig. 2.

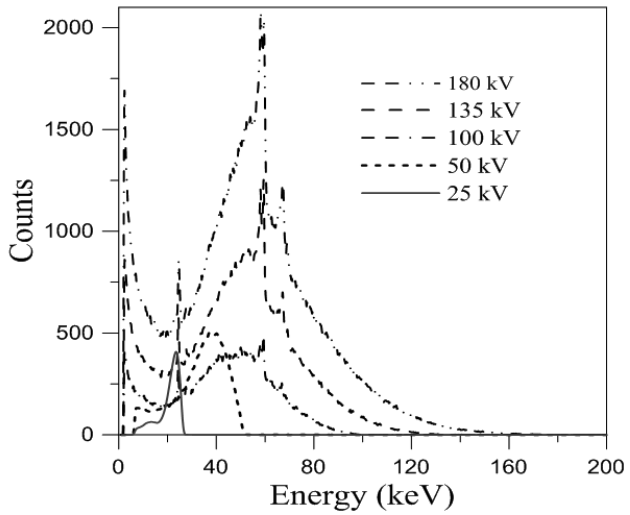


Fig. 2. The X-ray spectrum for different applied kV

Sometimes adding filter is used to get a precise beam quality with a finite HVL. In this work, adding filter affected the spectra of the X-ray beam at 180 kV, but the endpoint is was still equal the kV of the X-ray tube which reflects that using this method is a good tool for kV estimation as represented in Fig. 3. Fig. 4 shows the kV applied to the X-ray tube as a function of the endpoint spectrum where a linear shape was obtained. The slop of this linearity is the same calibration factor of the kV applied to the X-ray tube.

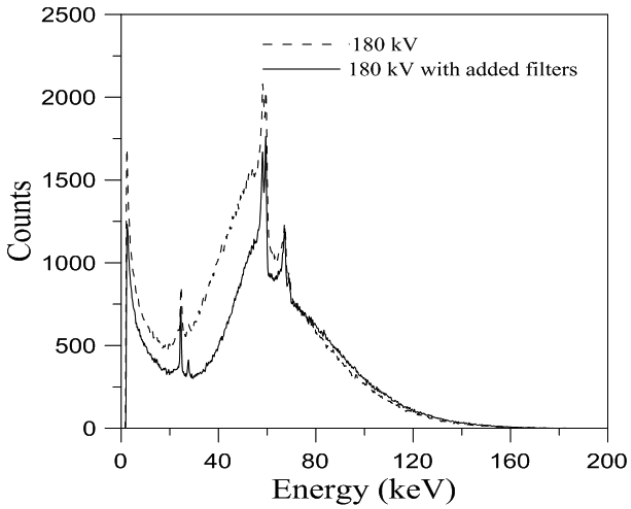


Fig. 3. The effect of the added filter on the X-ray spectrum at applied voltage180 kV

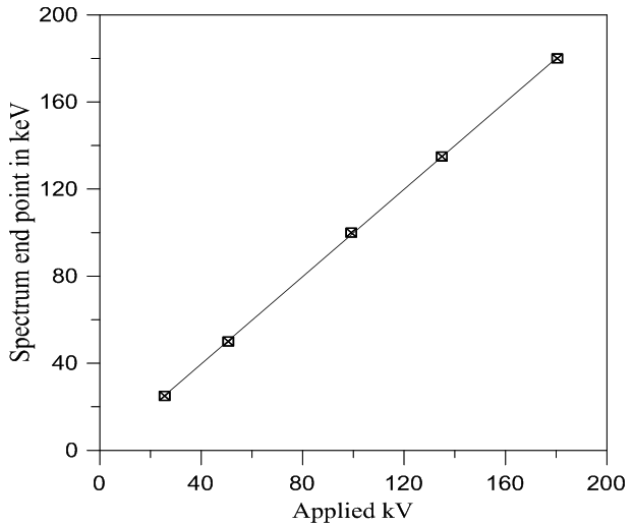


Fig. 4. Values of the end-point as a function of kV

The end point spectrum varies with applied voltage according to the relation of the following equation, with regression 99.9%:

$$E\ (keV) = 1.003 \cdot kV - 0.42 \qquad (1)$$

X-Ray Fluorescence(XRF) method

In this method, a filter of purity of 99.99% was used. The filter was supported with an angle of 45^0 of the X-ray beam while the measuring system was fixed with 90^0 to measure the energy by HPGD or the Fluorescence X-ray dose by the ionization chamber (see Fig. 1). Fig. 5 shows the Fluorescence X-ray of Cd and Pb filter as measured by HPGD.

This spectrum appears if and only if the kV applied to the X-ray tube, is ≥ the X-ray Fluorescence energy of the used filter. Moreover, the intensity of the Fluorescence x-ray will increase with the applied voltage increase.

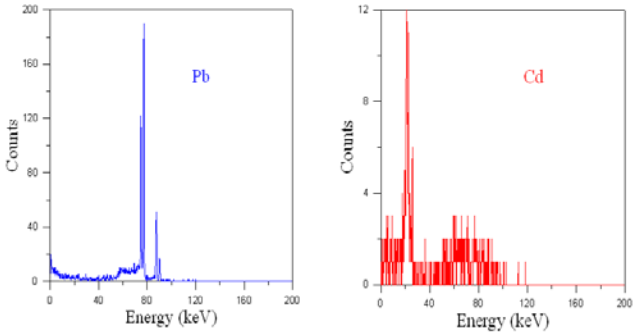


Fig. 5. Typical spectra of the XRF for Pb and Cd filters

Fig. 6 shows the emitted dose as a function of kV for Sn, Cd and Pb. The intercept of the linear fitting of XRF intensity is equal to the exact value of kV applied to the X-ray tube.

Values of the interception with X-axis of Fig. 6 with the applied voltage are represented in Fig. 7.

The linear fit of data in Fig. 7 extracted the following relation in equation given below, where the calibration factor of the applied voltage kV is 1.016.

$$E\ (\text{keV}) = 1.016 \cdot \text{kV} - 1.38 \qquad (2)$$

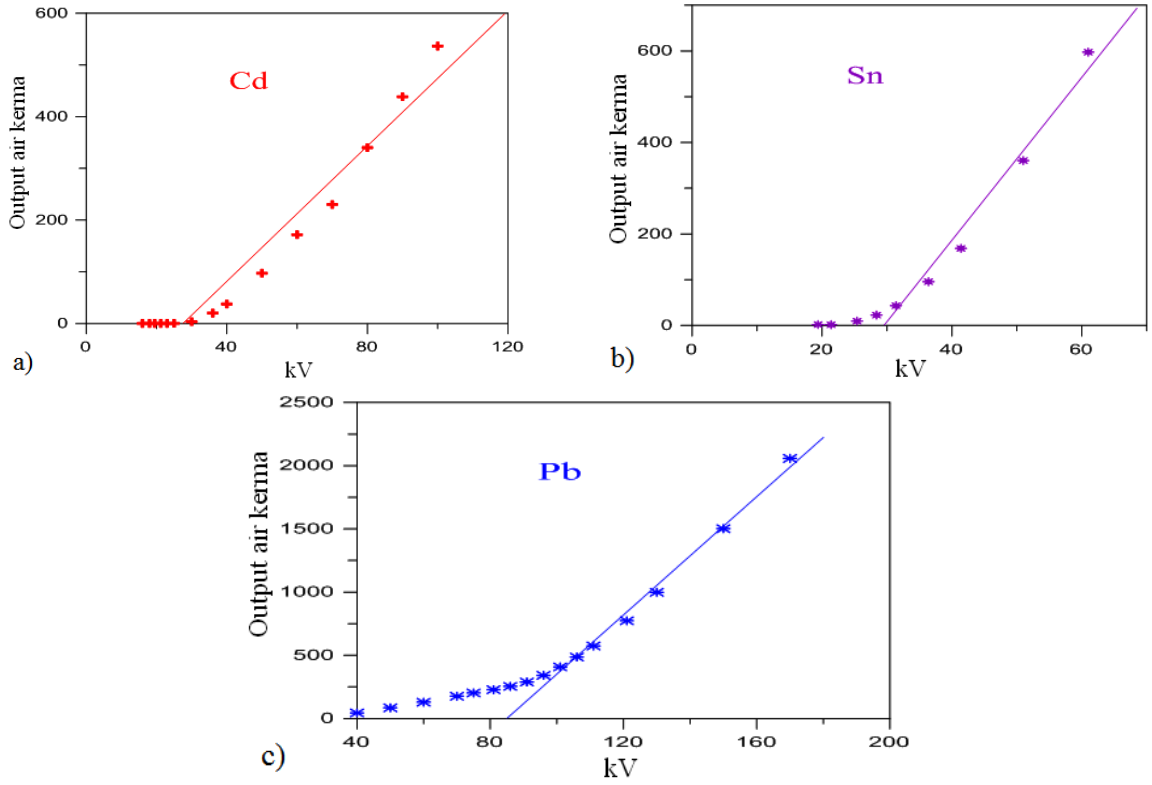


Fig. 6. XRF intensity as a function of applied voltage for Cd (a), Sn (b) and Pb (c)

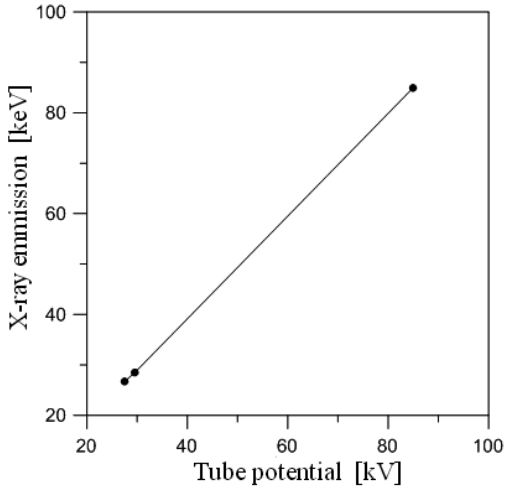


Fig. 7. Energy of XRF as a function of applied voltage kV

X-Ray mean energy determination

In this work, the mean energy for different beam quality X-rays were determined by different methods, by using HPGD spectra for a precise beam quality (direct beam or with additional filtration) from the center of the spectra, and by SPEKTR 3.0 software [12].

Table 1 presents the mean energy of the studied beam quality of the CCRI for both medium and low energy X-rays. From the table it can be noticed an agreement between the mean energy X-ray determined by different methods.

Table 1. Values of kV as measured by different techniques

kVp	**25**	**50**	**100**	**135**	**180**	**Method of Calculation**
End point (direct)	25.58	50.67	99.17	134.89	180.44	HPGD
End point (Filtered beam)	-	-	100.81	134.71	180.09	HPGD
Mean energy [keV] (direct)	22.67	37.43	49.73	52.79	54.09	HPGD
Mean energy (direct beam)	-	-	49	59.4	-	SPEKTR 3.0 program
Mean energy (keV) (Filtered beam)	-	-	50.2	54.79	56.5	HPGD
Mean energy (filtered beam)	20.71	32.75	50.76	67.9	-	SPEKTR 3.0 program

kV-keV relationship

Using Winxcom software, the linear attenuation coefficients of X-ray for Cu and Al were calculated and represented in Fig. 8.

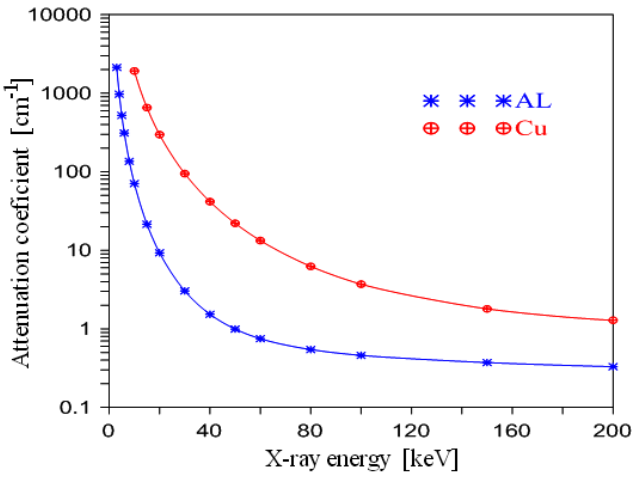


Fig. 8. Attenuation coefficient of X-ray for Cu and Al

Half-Value layer (HVL) of X-ray for Cu and Al were calculated and represented versus X-ray energies in Fig. 9.

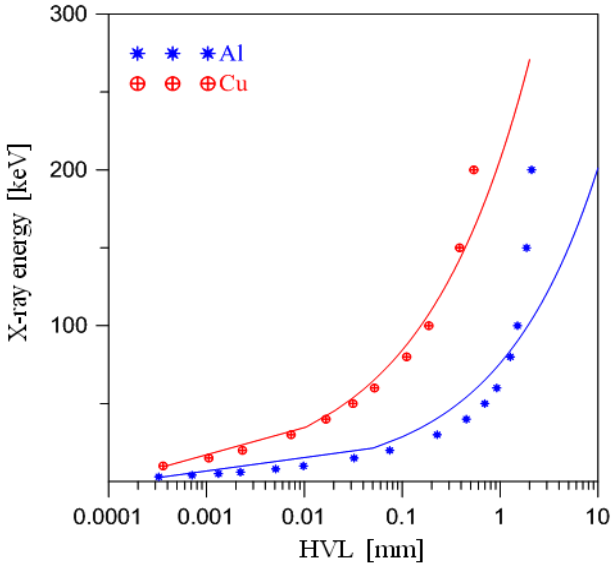


Fig. 9. HVL of X-ray for Cu and Al

From this figure an empirical relation of HVL- keV of X-ray was obtained as:

$$E_{(keV)} = 75.9(HVL)^{0.424} \text{ Al}$$

$$E_{(keV)} = 206.7(HVL)^{0.34} \text{ Cu}$$

From the above relation, one gets the mean energy of X-ray by the method of HVL. Mean energy was also determined using spectrum of HPGD.

Conclusions

From this work it can be concluded that the two methods used for kVp calibration of X-ray machines are applicable and convenient.

Adding filtration does not affect the determination of kVp by HPGD endpoint spectrum, but affects XRF emission.

The keV- kV relationship was obtained as a function of HVL in the commonly used filter Al and Cu.

The X-ray spectra measured by HPGD can be used for mean energy determination. The value of the mean X-ray energy determined was in a good agreement with that calculated by SPEKTR 3.0 software.

Calibration factor obtained by using HPGD method was more accurate than that determined by using the XRF method for the X-ray machine.

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