Applied Radiation and Isotopes 100 (2015) 60–64

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

kVp estimate intercomparison between Unfors XI, Radcal 4075 and a new CDTN multipurpose instrument

A.T. Baptista Neto*, B.B. Oliveira, L.O. Faria

Nuclear Technology Development Center – CDTN/CNEN, Av. Presidente Antônio Carlos, 6627 – Campus UFMG, Pampulha, Belo Horizonte 31270-901, MG, Brazil

HIGHLIGHTS

- We compare the kVp estimate between CDTN instrument and 2 different kVp meters.
- The new CDTN multipurpose instrument performance was found to be satisfactory.
- All instruments increase kVp estimative for increasing additional filtration.
- They are suitable for quality control routines in x-ray diagnostic radiology.

ARTICLE INFO

Article history:
Received 9 July 2014
Received in revised form
18 November 2014
Accepted 24 November 2014
Available online 26 November 2014

Keywords:
Radiation detector
Peak voltage
X-ray

ABSTRACT

In this work we compare the kVp estimate between CDTN multipurpose instrument, UnforsXI and Radcal 4075 meters under different combinations of voltage and filtration. The non-invasively measurements made using x-ray diagnostic and interventional radiology devices show similar tendencies to increase the kVp estimate when aluminum filters are placed in the path of the x-ray beam. The results reveal that the kVp estimate made by the CDTN multipurpose instrument is always satisfactory for highly filtered beam intensities.

1. Introduction

In response to the increasing use of ionizing radiation in medicine, to the risks therein involved and to the need of enforcing radiation-protection policies, many countries have issued technical regulations defining basic radiation protection requirements and guidelines for the use of devices that generate a series of radiation qualities. Special attention is given to x-ray equipment that is routinely used for both common diagnostic radiology and interventional radiology. The latter utilizes minimally invasive image-guided procedures to diagnose and treat diseases in nearly every organ system (IAEA, 2006).

The x-ray spectrum is defined as the energy distribution of the radiation produced in an x-ray exposure (Nickoloff and Berman, 1993). The determination of photon spectral distribution as a function of photon energy is usually necessary to completely characterize x-ray beams. However, performing these procedures requires significant time and experience (ICRU, 2005). Routinely, the practical characterization of an x-ray beam quality is based on the determination of other parameters, including the voltage applied to the tube electrodes, or kVp (Bushberg et al., 2012; IEC, 2005; IAEA, 2000; ISO, 1996).

The beam filtration modifies the quality of the x-ray beam by preferentially removing the low-energy photons in the spectrum; furthermore, higher Z materials cause further beam hardening (Seibert and Boone, 2005). Non-invasive kVp meters use this principle to relate the applied voltage to the x-ray emission equipment, forcing the beam to cross a metal sheet with enough thickness, therefore shielding most of the low energy photons. The mean energy of the photons remaining in the beam is tightly correlated to the applied voltage when the beam crosses two filters of different thicknesses (Joseph and Wilson, 1982; Aichinger and Kranberg, 1983; Ranallo et al., 1990).

Considering radiology exposures, the radiation quality influences the balance between image quality and dose applied to the patient because interactions between x-ray photons and tissue vary with photon energy. Metal filters are fitted to x-ray tubes to attenuate lower energy photons that would be completely

* Corresponding author.
E-mail addresses: annibal@cdtn.br (A.T. Baptista Neto), boliveira.mg@gmail.com (B.B. Oliveira), farialo@cdtn.br (L.O. Faria).

http://dx.doi.org/10.1016/j.apradiso.2014.11.019
0969-8043/

absorbed by patients without contributing to radiological examinations, unnecessarily adding to the examination dose (Martin, 2007). A filter equivalent to at least 2.5 mmAl is required by guidelines (IPEM, 2002), being oftentimes incorporated as standard accessory in medical x-ray tubes, but additional filters may be inserted. Once installed, filters in conventional radiographic units are seldom altered. However, during quality control procedures in x-ray equipment, we observed that, in most cases, when half-value layer lies below acceptance criteria and, consequently, the patient dose is relatively high when compared to limit values, the cause is usually related to the removal of this additional filtration during x-ray equipment corrective maintenance.

Voltage meters, when used in procedures to control the quality of x-ray emitting equipment, must correctly and unambiguously operate under distinct filtration conditions. Ambiguities occur when measurements obtained for high voltages and low filtration rates are similar to those obtained for lower voltages and high filtration rates.

CDTN has recently developed a multipurpose instrument capable of non-invasively measuring the air kerma, the half-value layer and the voltage of radiation emitting equipment. In order to validate the voltage estimates, the above-mentioned instrument was compared to the UNFORS model Xi R/F and the Radcal model 4075 R/F meters, for different voltage and filtration conditions.

Here we report that although all instruments show a similar tendency to increase the kVp estimate when aluminum filters are placed in the path of the x-ray beam, they may all be satisfactorily adopted in quality control routines of x-ray equipment by means of estimation of the applied voltage.

2. Materials and methods

Tests were carried out using a Pantak Seifert model 320 HS x-ray machine and the same setup was adopted for all instruments under comparison. This device's inherent filtration was estimated to be 0.18 mmAl by means of the extrapolation method described in ISO 4037-1. Each meter was carefully positioned at the x-ray beam center and 100 cm distant from focal spot. We have placed aluminum filters and two lead collimators at the radiation beam output in order to reduce the scattered radiation and the beam cross section. The current applied to the x-ray tube has been kept at 20 mA throughout the irradiation process of all meters.

2.1. The Unfors model Xi R/F

The Unfors Xi consists of a base unit and several different external detectors for Radioscopy/Fluoroscopy (R/F), mammography (MAN), Computer Tomography (CT) and others. Communication between detector and base unit is purely digital, thereby minimizing sensitivity to mechanical or electrical stress. The R/F detector has two sensors: R/F High is designed for conventional, high dose rate measurements; R/F Low is designed for low dose rate measurements. In this work, during measurements, we used the Unfors model Xi R/F Low sensor.

2.2. The Radcal Corporation model 4075 R/F

The Radcal Corporation 4075 R/F consists of a base unit with two internal detectors placed under different filtrations. The ratio between these two internal detectors signals is used to determine the peak voltage and, according to the manufacturer guide, it is independent of the tube current or the instrument focal spot-distance (d_{f-i}). The detectors are centrally positioned and are able to measure voltages in the 55–145 range.

2.3. The CDTN multipurpose instrument

The new multipurpose instrument developed in the CDTN's Calibration Laboratory consists of a PVC square base plate where a depression holds a radiochromic film that detects the incoming radiation. One lead and one acrylic plate are used to shield against unwanted scattered radiation. Sixty-five hollows enable the use of filters of different materials and thickness, necessary to estimate air kerma, peak voltage and half-value layer. Details of the instrument and its operation have been presented by Baptista Neto and Faria (2014).

Precautions in handling radiochromic films, outlined by Butson et al. (2003), were observed. Additionally, in order to reach chemical stability, film samples remained undisturbed for 24 h before the beginning of the readout process. Exposure to light was minimized by handling films in opaque envelopes both before and after irradiation and scanning (Butson et al., 2002).

The characteristics of the Gafchromic® XR-QA2 radiochromic film for kV image dose measurement have been investigated by Giaddui et al. (2012). For the range of energy selected by the authors, the dependence on energy remained below 10%. Al-Okshi et al. (2013) found virtually coincident dose–response curves when testing the Gafchromic® XR-QA2 film for 60 kV, 80 kV and 120 kV beams, which suggests weak dependence on energy within the selected energy range.

Films were scanned using the ScanJet 4C Hewlett Packard scanner at 600 dpi resolution, in color image mode. Files were saved as Tagged Image File Format (TIFF) and analysis of color intensity was performed with the ImageJ application program. Statistical tools that allow reduction in the measurements standard deviation were used in the radiochromic films analysis, as suggested by Baptista Neto et al. (2014).

3. Results and discussion

When an x-ray beam crosses an attenuating medium, the relationship between input and output radiation doses varies according to the radiation energy emerging from the tube. Thus, one of the basic principles adopted to non-invasively relate the applied voltage to the x-ray emission equipment is to force the beam to cross a metal sheet with enough thickness, in order to shield most of the low energy photons. The mean energy of the remaining photons is then tightly correlated to the voltage applied to the electrodes and may be deduced from the relationship between the beam intensities obtained when the beam crosses two filters of different thicknesses (Joseph and Wilson, 1982; Aichinger and Kranberg, 1983; Ranallo et al., 1990b). In this context, we compare the peak-voltage results by means of a substitution method with three distinct non-invasive devices: a voltage meter manufactured by Radcal Corporation, model 4075 R/F, a multipurpose electronic instrument manufactured by Unfors model Xi and a multipurpose instrument assembled at the CDTN Calibration Laboratory. It is important to observe that the use of this method presupposes that small fluctuations could not be perceived, since the waveform is not monitored.

3.1. Unfors model Xi R/F

All measurements were made using the R/F low detector due to the low current levels prevailing during x-ray exposure. Table 1 shows Unfors model Xi R/F's response to different x-ray conditions. Additional filtration varied from 0 to 5 mmAl and nominal voltage was investigated from 40 to 100 kVp, as shown in Table 1. For 90 and 100 nominal kVp values and no additional filtration, the instrument exhibited the “HiFilt” message.