

## The Use of Fricke Dosimetry for Low Energy X-Rays

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### ABSTRACT

*The performance of four X-ray qualities generated in a Pantak X-ray machine operating at 30-100 kV was determined with a parallel-plate ionization chamber and a Fricke dosimeter. X-ray qualities used were those recommended by Deutsch Internationale Normung DIN 6809 and dose measurements were carried out with Plexiglas<sup>®</sup> simulators. Results have shown that the Fricke dosimeter can be used not only for soft X-ray dosimetry, but also for the maintenance of low-energy measuring systems' calibration factor.*

**Key words:** Radiation dosimetry, soft X-rays, Fricke dosimeter

### INTRODUCTION

Cobalt-60 irradiators, linear accelerators and soft X-ray machines have been routinely used for the treatment of malignant tumors in hospitals worldwide. The perspective of healing malignant tumors is dependent on the magnitude of the radiation dose applied during therapy. In this regard, underdosage may jeopardize the tumor control probability. They are difficult to discover, may be only detected after a relatively long time and, therefore may involve a large number of patients. On the other hand, too high radiation doses, despite their high probability of success in the killing of a tumor, increase the frequency of late effects in treated patients [1].

In general, optimum radiation dose levels for radiotherapy vary with the type of tumor and radiation source specifications [2]. On the basis of technical reports of inspections carried out by CNEN, the green light is given to clinics and

hospitals where deviations between actual doses applied to patients and those measured during inspections are of 3% or less, the same value as those published in the scientific literature [3].

Although the 3% uncertainty can be seen as quite adequate for radiotherapy procedures, CNEN's inspections are not extended for soft X-ray machines, so that their control is left to the clinics' physicians. Based on CNEN's recommendations and the assumption that the measuring system being used shows no changes in response/sensitivity during the 12 months following its calibration [4], this control is based on dosimetry measurements carried out with a parallel-plate ionization chamber.

Therefore there is no national intercomparison program for therapeutic X-ray machines. On the other hand, the transportation of measuring systems and standards in a continental country such as Brazil and the costs incurred must be appreciated.

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The present paper shows how low-energy Fricke dosimetry can be used for the quality control of soft X-ray machines and how the calibration factor of measuring systems used for soft X-ray dosimetry can be maintained.

## MATERIALS AND METHODS

A 160-kV Pantak X-ray machine was used for the irradiation of a reference measuring system and the Fricke dosimeter. The high voltages applied to the X-ray tube were determined with an Eurisy (HP)Ge X-ray spectrometer for the radiation qualities shown in Table 1, as specified by the *Deutsches Institut für Normung* [5]. Half-value layers were determined with 99.99% pure aluminum filters, and the mean energy of the radiation beams was derived from the mean averages for the radiation qualities by the *Deutsches Institut für Normung* [6].

A measuring system comprising an NE model 2670-A electrometer and a PTW model 2532/3C ionization chamber (England), designed to measuring absorbed dose due to x-rays beams generated by tube potential ranged from 10 to 100 kV, was used for dosimetry purposes. Irradiated Fricke solution's optical density was measured in a quartz cuvette (1-cm path length) with a UV-VIS (150 – 800 nm) Beckman Coulter DU 640 spectrophotometer (EUA), and the temperature was measured with Eutechnics digital thermometer Model 4400 (EUA). The Fricke solution itself was synthesized with 0.392 g of hexahydrated ferrous-ammonium sulfate ammonium P. A. ( $10^{-3}$ , MERCK), 0.060 g of sodium chloride P. A. ( $10^{-3}$ , MERCK) and 22 mL of concentrated sulfuric acid P. A. (MERCK) diluted in Milli-Q (18.2 MΩ.cm) water in a 1,000-mL volumetric balloon (corresponding to a total mass of 1,022.7 g). The water-acid system was previously irradiated at 10

Gy to eliminate impurities [7]. Once the solution was ready, 3.5-mL aliquots were transferred to several 6-mL sterilized "vacutainer" plastic vials. The experimental setup for irradiation of the ionization chamber and the Fricke solution is shown in Fig. 1. The ionization chamber and the plastic vials were placed on the surface of a Plexiglas® simulator with 110 mm x 110 mm x 80 mm. Finally, both measuring systems were irradiated with the radiation qualities presented in Table 1.

The ionization chamber was positioned on the simulator with the center of the entrance window (sensitive volume) perpendicular to the radiation beam's central axis. The dose absorbed in water,  $D_w$ , in grays (Gy) was obtained from the average of five readings,  $M_p$ , through equation. (1).

$$D_w = N_D * M_p * K_p \quad (1)$$

Where,

$N_D$  – calibration factor in terms of dose absorbed in water.

$M_p$  – reading obtained with the measuring system in its own units when the ionization chamber is in the simulator.

$K_p$  – correction factor for air density relative to reference conditions (20.00 °C e 101.33 kPa), as calculated by equation (2).

$$k_{TP} = \left( \frac{273,15 + T}{293,15} \right) \left( \frac{101,33}{P} \right) \quad (2)$$

where T and P are the temperature in °C and pressure in kPa, respectively, in the vicinities of the chamber during the measuring procedure.

Fig. 1. Irradiation set up for ionization chamber (a) and Fricke solution (b)

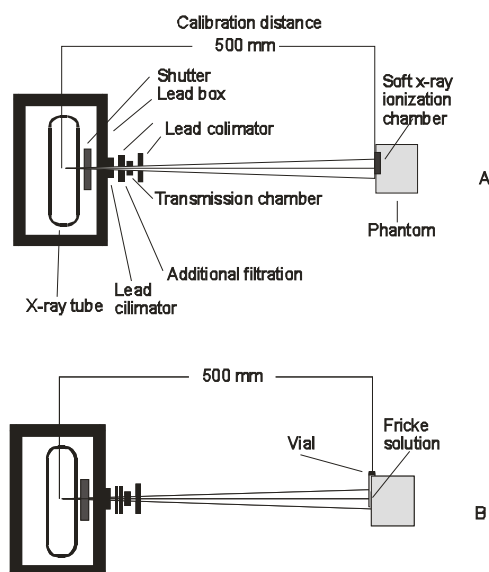


Figure 1 - ionization chamber irradiation (A) and fricke dosimeter irradiation (B)

Table 1 - X-ray qualities recommended by the DIN 6809 [6].

High voltage (kV)	Additional filtration (mm Al)	Half-value layer (mm Al)	Mean energy (keV)
30	0.447	0.370	19.7
50	0.894	1.021	29.4
70	3.965	3.110	42.1
100	4.164	4.520	52.2

The polyethylene tubes containing the Fricke solution were half-embedded in the Plexiglas<sup>®</sup> simulator at a distance of 500 mm relative to the X-ray tube focal point, as shown in Fig. 1b. The geometric center of the solution volume was taken as the reference point. The Fricke dosimeters were irradiated with a 50-mm wide circular field and a radiation dose of 40.0 Gy, as determined with the ionization chamber. Doses obtained with the Fricke solution were calculated in accordance with International Atomic Energy Agency recommendations, IAEA TRS 178 [8], as specified by equation (3) [7],[8].

$$D_W = \frac{\Delta OD \cdot N_A}{G(\text{Fe}^{3+}) \cdot \varepsilon (t^\circ \text{C}) \cdot d \cdot \rho \cdot f_1 \cdot f_2} \quad [\text{Gy}] \quad (3)$$

In this equation,

$$f_1 = 1 + 0,0069(T_i - 25) \quad (4)$$

$$f_2 = 1 + 0,0012(T_i - 25) \quad (5)$$

and  $\Delta OD$  – change in the irradiated solution's optical density relative to the non-irradiated solution at a wavelength of 304 nm (absorption peak of  $\text{Fe}^{3+}$ ).

$N_A$  – Avogadro's number

$G(\text{Fe}^{3+})$  – chemical yield for the irradiation energy

$\varepsilon$  – molar extinction coefficient

$d$  – optical pathway

$\rho$  – solution density

$T_i$  – solution temperature during irradiation ( $^\circ\text{C}$ )

$T_1$  – solution temperature during measurement ( $^\circ\text{C}$ ).

In the present work values of  $218.7 \text{ m}^2 \text{ mol}^{-1}$  for the molar extinction coefficient of  $\text{Fe}^{3+}$  at  $25^\circ\text{C}$  [9] and of  $1,022.7 \text{ kg}\cdot\text{m}^{-3}$  for the solution density [7] were assumed. Moreover, the cuvette utilized in the spectrophotometer had an optical pathway of 10 mm and factors  $f_1$  and  $f_2$  are those described by A. Olszanski et al [7].

Finally the values for the chemical yield  $G(\text{Fe}^{3+})$  are those recommended by ICRU Report 17 for dosimetry procedures for radiations generated with

high voltages between 5 and 150 kV [10], shown in Figure 2. In this figure, the mean values of  $G(\text{Fe}^{3+})$  evaluated by several authors published by ICRU Report 17 (Table 2) were fitted to specify the

radiation qualities used in the present work as shown in Fig. 2.

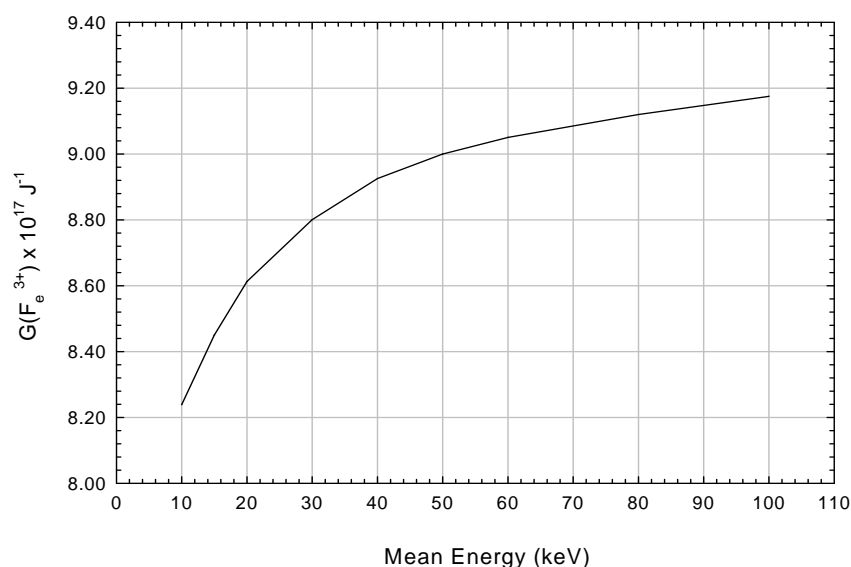


Figure 2 - Chemical yield  $G(\text{Fe}^{3+})$ . Fitted data taken from the ICRU Report 17[10].

Table 2 - Chemical yield values used to calculate absorbed doses.

Potencial (kV)	$G(\text{Fe}^{3+}) \times 10^{17} \text{ J}^{-1}$
30	8.61
50	8.80
70	8.93
100	8.99

For instance, for the radiation quality produced at 70 kV, the absorbed dose may be calculated by equation. (6):

$$D_{W70kV} = (\Delta OD \times 301,5) / f_1 f_2 \quad [\text{Gy}] \quad (6)$$

## RESULTS AND DISCUSSION

Figure 3 shows doses absorbed in water evaluated with the ionization chamber and the Fricke

dosimeter for the radiation qualities presented in Table 1.

No investigation was carried out to determine the total uncertainty in the determination of the dose with the ionization chamber or the Fricke dosimeter. Nevertheless, based on the chamber's calibration factor uncertainty (3.5%) and the Fricke dosimeter's long term stability (3%), and by taking the total uncertainty as the square root of the sum of the squares of each individual uncertainty, it is expected that dose values determined by both measuring systems should not deviate by more than 4.6%.

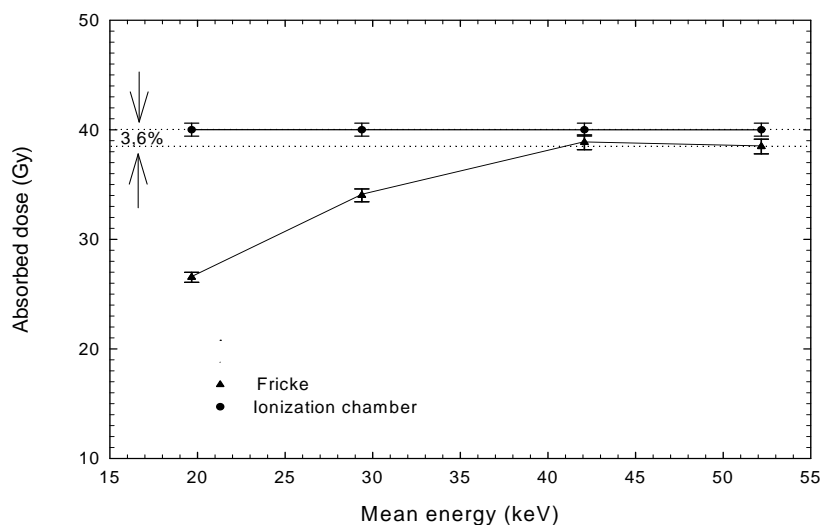


Figure 3 - Fricke dosimeter response as a function of radiation energy for 40 Gy.

This value is very conservative when compared with the uncertainty evaluated by Souza [11,12] (3.5%) in the determination of absorbed dose of soft x-rays equipments using the same spectrophotometer as the one used in this work.

For radiation qualities corresponding to 50 and 30 kV (29.4 – 19.7 keV) doses determined with the Fricke dosimeter are lower by 18 and 51 %, respectively, than those obtained with the ionization chamber. This can be explained by the beam attenuation in the vial's walls, as well as to the dose gradient due to the Fricke solution itself.

Preliminary Monte Carlo modeling using Pirex<sup>®</sup> and polyethylene Fricke's vials has shown that the attenuation suffered by the radiation beam when it interacts to the solution vial's walls and solution's depends on the vial material and thickness as well as the volume of the Fricke solution inside the vial. Such data are not yet published because further experiment is going on by using plastic phantoms made of a thinner layer of Polyethylene filled with water to evaluate absorbed doses with ionization chambers and Fricke dosimeter, as suggested by Austerlitz [13].

Although the Fricke dosimeter has been used to measure absorbed dose in an absolute way, the measurements performed with the PTW model 2532/3C ionization chamber were necessary to

show the energy's threshold in which the Fricke dosimeter can be used based on the conventional formalism of absorbed dose calculation.

The 70-kV radiation quality was taken as a standard for the maintenance of CRCN's calibration factors for the following reasons: (a) it is in the energy range where the Fricke dosimeter response shows a relatively low energy dependence, and (b) this quality presents a half-value layer similar to that employed by Brazil's National Laboratory for Ionizing Radiation Dosimetry, that adopts reference qualities for the calibration of Bureau International des Poids et Mesures, Sèvres ionization chambers [14].

Therapeutic X-ray machines operate with high dose rates, which enable the utilization of Fricke dosimetry to be applied to them. Moreover, the Fricke dosimeter components are small enough to be sent by mail to clinics and hospitals all over the country. The adoption of this procedure would ensure that a comprehensive dose control in radiotherapy units be achieved at a much lower cost than that associated with CNEN's conventional inspections.

The dependence of the Fricke dosimeter with the energy of the x-ray beam in the range of 30 to 50 kV tube potential can be used to perform quality control of half-value layers of soft x-ray

machines. This can be done by measuring the output of an x-ray machine with Fricke dosimeter at two different kilovoltages, e.g., at 100 kV and 30 kV, and calculating the absorbed dose by using the predicted values of the HVLs for such equipment to correct the Fricke dosimeter energy dependence showed in Figure 3. If there are an agreement between predicted and measured output values for both kilovoltages, the predicted value of the HVL for the lowest energy x-rays is correct. If only the output values for 100 kV agree, the HVLs for such machine should be reevaluated. Pilot measurements performed with three different types of therapeutic soft X-rays equipment in northeastern Brazilian's hospitals has shown the feasibility of the Fricke system used in this work. Additionally, the uncertainty in the determination of the absorbed dose does not exceed 3% when the values of the optical densities is higher than 0.14 [11].

## CONCLUSIONS

From what has been presented so far, the following conclusions may be drawn:

For x-ray produced by tube potential ranged from 70 to 100 kV (42 keV to 52 keV) the Fricke dosimeter can be employed for the quality control of soft X-ray machines for on site measurement combined with postal delivered.

For energies below 42 keV the attenuation of the X-ray beam caused by the vial wall and the Fricke solution has to be considered in the traditional formalism to calculate absorbed dose with the Fricke dosimeter. However, the dependence of the Fricke dosimeter with the energy of the X-ray beam can be used to perform quality control of half-value layers. This can be done by measuring and comparing the output values of an X-ray machine with Fricke dosimeter and an ionization chamber at two different kilovoltages.

For the 42 to 52 keV energy range Fricke dosimetry can be employed for the maintenance of calibration factors from measuring assemblies used in the dosimetry of soft X-ray machines.

## RESUMO

Neste trabalho, o dosímetro Fricke foi utilizado para verificação dos rendimentos de quatro

qualidades de radiação produzidas por um aparelho de raios-X Pantak de 160 kV com potenciais entre 30 e 100 kV. Para tanto, foram utilizadas as qualidades de radiação recomendadas pela "Deutsh Internationale Normung" DIN 6809. As medidas foram realizadas em simuladores de plexiglas. Os resultados obtidos demonstraram que o dosímetro Fricke pode ser utilizado não apenas para a dosimetria desses equipamentos, mas também, para a manutenção do fator de calibração de sistemas de medidas para baixas energias.

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