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High-sensitivity radiation detector for low dose level radiological applications

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Radiation dosimetry by Fricke gel was largely used, generally focused and optimized for radiotherapy applications therefore involving relative high dose levels. Fricke gel dosimetry has several advantages, like dose rate and LET almost independence, 3D mapping, among other. This work presents a novel Fricke gel dosimeter optimized for low dose levels. Several chemical composition were studied varying concentrations of sulfuric acid (H_2SO_4), ferrous ammonium sulphate ($(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$), benzoic acid ($C_7H_6O_2$) and Xylenol orange ($C_{31}H_{32}N_2O_{13}S$). Samples were analyzed by light transmission and absorbance. Sensitivity for low dose levels was significantly improved testing typical radiology setups. Comparisons with ionization chamber showed good agreement. Thus, remarking reliability of the developed system as promising tool for low-level dosimetry.

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1. INTRODUCTION

Ionizing radiation is daily used for therapeutic and diagnostic medical procedures. Then, it has to be considered the effects and risks of radiation exposure. Actually, reliable dosimetry in medical practices has to be carefully investigated [1][2].

Fricke gel dosimetry (FGD) [3][4][5] has a lot of advantages, mainly 3D continuous mapping [5], tissue-equivalence and beam quality independence [6][7][8].

The present study presented briefly a novel Fricke gel dosimeter with high sensitive at low dose levels. Several chemical compositions were studied for performance improving [6][9][10]. Comparisons with conventional dosimetry indicated feasibility and reliability [2][10]. As preliminary application in clinics, it was used a computed tomography (CT) configuration.

2. MATERIALS AND METHODS

A conventional X-ray tube was used as radiation source providing wide range of variations of both current and voltage for configuring different beam qualities.

Fricke gel dosimeters were prepared in standard vials and optically analyzed by spectrophotometry (UNICO 1205 Vis equipment), using samples of ultra pure (tridistilled) water UV quartz vials as absorbance reference pattern. A calibrated ionization chamber (PTW TN 30013) was used as reference for dosimetry. Phantoms with certain properties allowed insertion of both Fricke gel vials and ionization chamber.

The composition used as starting point [10] consisted of 124.38 mM porcine skin gel, 0.6 mM ferrous ammonium sulphate, 8 mM sulfuric acid, 2 mM Xylenol orange and 96% ultra pure water. Chemical compositions was modified varying the components one at the time characterizing sensitivity and stability. Dose-response linearity and reproducibility were studied by several experiments using different chemical compositions and solution batches [11].

An adapted Computed Tomography (CT) facility was used for evaluating the performance in radiology. There were separated some samples from each elaboration batch to be used for calibration curves measurements. A linear regression model was applied for dose-response characterization. Finally, absorbed dose comparisons were accomplished traducing both FGD and ionization chamber read outs to dose in water.

3. RESULTS AND DISCUSSIONS

There were performed a large quantity of tests varying chemical composition attempting to evaluate optimal concentration of each component. As example of the obtained results for component variations Figure 1 shows the effect of H_2SO_4, $FeSO_4$.

Similarly was studied the effect of varying the concentration of all other components as well as the addition of 5 mM of benzoic acid improving stability and sensitivity. Finally, the composition considered as the optimal one [11], called *Benzoic Fricke Gel Dosimeter (BFGD)*, consisted of: 5 mM $C_7H_6O_2$, 29 mM H_2SO_4, 0.3 mM $(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$ and 0.1 mM Xylenol orange in a gel matrix of 124.38 mM with 96% of volume with ultra pure water.

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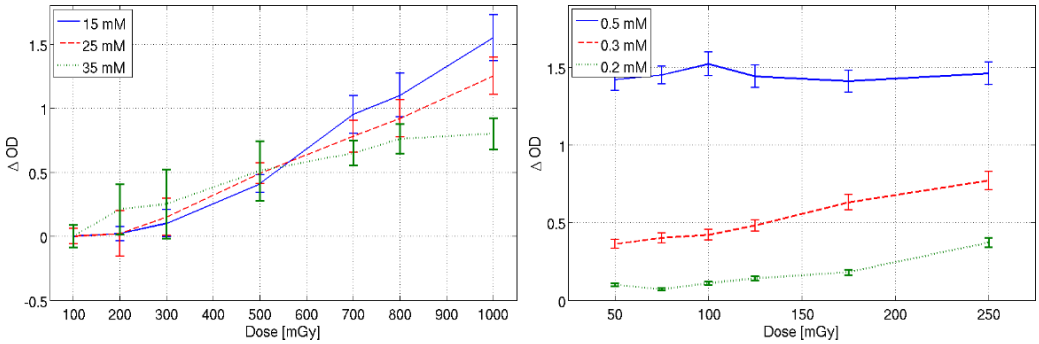

Figure 1: FGD dose-response modifying H_2SO_4 (left) and $FeSO_4$ (right) concentrations.

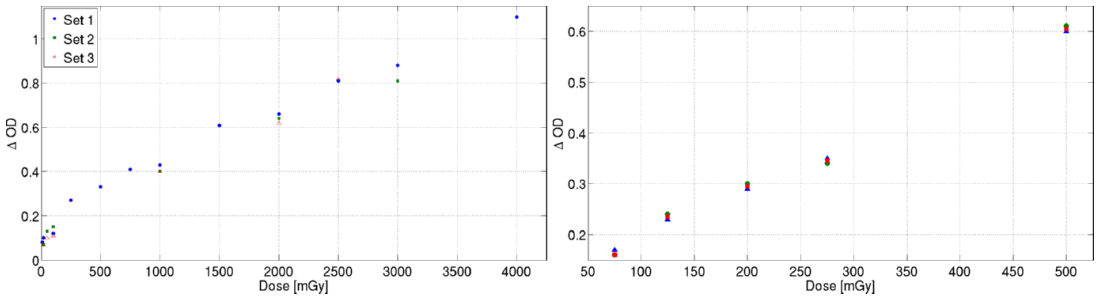

Figure 2: Dose-response reproducibility (left) and beam quality dependence (right).

Dose-response linear trend and reproducibility along with beam quality dependence were studied for different solution batches. The obtained results are shown in Figure 2.

Then, it was investigated dose-response for different beam qualities corresponding to typical radiological practices.

Dedicated experiments highlighted the performance of the developed system for clinical-like applications. After that Fricke gel samples were placed at measuring location inside cylindrical water-filled acrylic phantoms and tomography scanning was carried out according to irradiation the set up sketched in Figure 3.

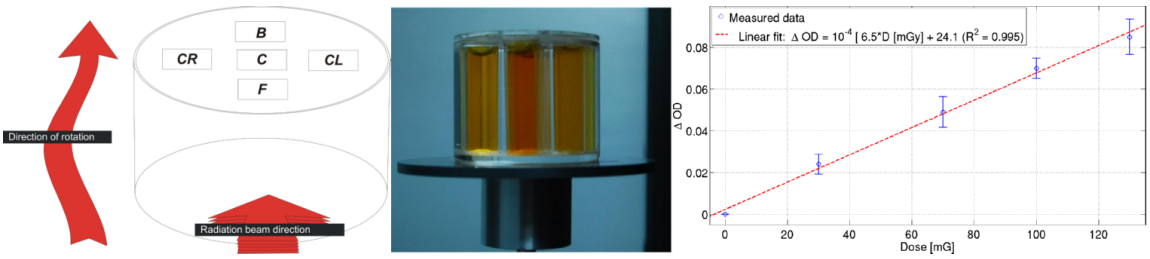

Figure 3: Tomography scanning set up for irradiation of Fricke gel samples indicating center (C), front (F), bottom (B), left (CL) and right (CR) sample positions (detector perspective).

The calibration curve obtained for tomography scanning is also shown in Figure 3, obtaining a linear correlation coefficient of $R^2 = 0.99$, then absorbed dose was directly assessed for the whole CT scanning measuring at the indicated location inside water-equivalent phantoms. The obtained results are reported in Table 1.

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Vial Location	Fricke Dosimeter	Ionizing Chamber
Rigth (CR)	(102.3 ± 3.1)	(100.1 ± 0.1)
Left (CL)	(121.0 ± 4.5)	(123.7 ± 0.2)
Center (C)	(131.0 ± 3.1)	(134.0 ± 0.1)
Front (F)	(74.5 ± 8.2)	(78.6 ± 0.1)
Bottom (B)	(94.2 ± 6.4)	(100.6 ± 0.2)

Table 1: Estimation of absorbed dose (in mGy) with Benzoic Fricke gel dosimeter and ionization chamber for μCT scanning.

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4. CONCLUSIONS

According to the obtained results, it can be stated that the novel Fricke gel dosimetry system developed for low dose level applicaions proved to exhibit the desired linear response and as well as high sensitivity in the range of 50 to 3000 mGy, at least. Actually, it was shown that dose response values were well distinguishable from the background. Furthermore, as quantitative dosimetry system its performance was similar to conventional dosimetry system.

Finally, as general comments it might be remarked that the developed dosimetry system attained surely high dose sensitivity enough to be considered as a potential useful tool for radiology quality assurance.

Acknowledgments

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