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Optical analysis of gel dosimeters: Comparison of Fricke and normoxic polymer gels

G. Gambarini [a,b,*], M. Carrara [a,d], M. Mariani [c], L. Pirola [a], S. Tomatis [d], M. Valente [a,b], E. Vanossi [c,b]

[a] Department of Physics of the University, Milan, Italy
[b] National Institute of Nuclear Physics (INFN), Milan, Italy
[c] Department of Nuclear Engineering, Polytechnic of Milan, Italy
[d] Department of Physics, National Cancer Institute of Milan, Italy

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Abstract

The dosimetry method based on optical analysis of gel layers has been experienced utilising both Fricke and polymer (normoxic) gels. The aim of the work was that of investigating the potentiality of a normoxic polymer gel and of performing a further verification of the reliability of Fricke gel dosimeters. Optical absorbance was measured, both with a spectrophotometer and by imaging light transmittance detected with a CCD camera. The results of the study of sensitivity, linearity of the response and reproducibility of the polymer gel dosimeter have shown acceptable performances, except for doses below 2 Gy. The linearity range extends up to 20 Gy. On the other side, dose images and profiles have shown noticeable differences when compared to those calculated or measured with ionisation chambers or Fricke gel dosimeters. Such Fricke dosimeters have given further confirmation of their reliability.

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1. Introduction

The method for in-phantom dose imaging by means of optical analysis of gel dosimeter layers has proved to give reliable results, both for photon dose imaging and for secondary-dose separation in thermal/epithermal neutron fields. The method is based on the detection, by means of a CCD camera, of grey-level (GL) images of the light transmitted by gel layers before and after irradiation. To this purpose, a suitable imaging apparatus has been designed and assembled in the laboratory [1]. Recently, improvements in the set up of the instrumentation and in the method for image acquisition and analysis have been performed [2,3], including the development of a suitable software for image processing [4].

The optical technique has been initially developed for Fricke-xylenol-orange-infused gel dosimeters as an alternative to magnetic resonance imaging (MRI). In fact, MRI requires very complex and expensive instrumentation that is found in almost all hospitals, but whose availability for dosimetry purposes is scarce. On the other hand, the optical imaging technique can be performed with simpler and cheaper instrumentation. Moreover, differently to MRI, the optical apparatus, consisting in a plane illuminator and a CCD camera, is transportable and can be settled near the irradiation unit. It is therefore possible to complete dosimeter analysis before diffusion effects become significant. In fact, the main inconvenience of Fricke gel dosimeters consists of ferric ion diffusion that causes a

* Corresponding author. Address: Dipartimento di Fisica dell'Università, via Celoria 1620133 Milano, Italy. Tel.: +39 02 50317243; fax: +39 02 50317630.
E-mail address: grazia.gambarini@mi.infn.it (G. Gambarini).

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smearing effect of images and a non-negligible alteration of measured dose values if the time between irradiation and analysis is not short enough.

In order to avoid diffusion and consequent distortion and loss of spatial information, gel-dosimetry research is now studying a different kind of gel dosimeters, in which absorbed dose induces a polymerization of its constituent materials (polymer gels) [5,6]. Among different possible dosimeter shapes (e.g. cylinders, layers), investigations regarding dose images reliability were here oriented to polymer gel layers. In fact, the layer configuration has been proven to be convenient in some situations, for example when phantoms are exposed to neutron fields [7]. A particular normoxic polymer gel was investigated, containing an antioxidant, whose role is that of scavenging the oxygen in the gel [8]. As a matter of fact, oxygen inhibits free radical polymerisation and therefore produces changes in the dosimeter response.

Aim of this study was to compare advantages and disadvantages of Fricke and normoxic-gel dosimeters. Thus, after having analysed them with a spectrophotometer and imaged with the CCD camera, the reliability of dose images and depth-dose profiles obtained with the two types of gel dosimeter was investigated.

2. Materials and methods

2.1. Gel dosimeter preparation

The composition of Fricke gel dosimeters is: Agarose [$C_{12}H_{14}O_5(OH)_4$] in the amount of 1% of the final weight, ferrous sulphate solution [1 mM $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], sulphuric acid [25 mM H_2SO_4] and xylenol-orange [0.165 mM $C_{31}H_{27}N_2Na_5O_{13}S$]. Fricke gel preparation was performed following the previously optimized protocol and utilising the apparatus suitably set up for Agarose gel dosimeters [9].

Regarding polymer gel dosimeters, some compositions were explored. The recently proposed MAGIC gel [10], in which oxygen is bound in a metal-organic complex, was initially studied. In fact, in MAGIC gels the trouble of oxygen inhibition, encountered with the other polymer gel dosimeters, was eliminated. Finally, another polymer gel was chosen, due to its increased dose sensitivity [11]. Its composition was: powder gelatine (type A, 300 bloom, Sigma–Aldrich) in the amount of 4%, 5% or 6% of the final weight, acrylamide [3% w/w $CH_2{=}CHCONH_2$], N′N metilenebisacrilamide [3% w/w $(H_2C{=}CHCONH)_2CH_2$] and tetrakis (hydroxymethyl) phosphonium chloride (THP) [2 mM $(CH_2OH)_4PCl$]. Highly purified and deionised water [H_2O] was utilised for all preparations.

Fricke and polymeric dosimeters obtained with gelatin in amount of 4% and 5% were in form of layers, 3 mm thick, having rectangular shape (11 cm × 5 cm). The gel was contained in structures consisting of two transparent sheets of polystyrene, held to a polystyrene frame. two small holes made on the frame allowed introducing the dosimeter solution by means of a syringe, before it hardened as a gel. Polymeric dosimeters with 6% weight amount of gelatin could not be realized due to their too high compactness also before gelling. In fact, it was not possible to inject them through the 1 mm diameter holes.

Moreover, cuvettes (1 cm optical path) were filled with polymeric-gel obtained with gelatin in weight percentage of 4%, 5% and 6% in order to perform spectrophotometric analysis.

2.2. Instrumentations for gel dosimeter analysis

Light transmittance of polymer gels realized in the different gelatin concentrations and placed in the cuvettes was evaluated by means of a commercially available spectrophotometer (Lambda 5, Perkin Elmer Inc., Fremont, CA, USA).

Gel-layers were analysed with a suitably developed imaging system. This apparatus consisted in a plane light source and a CCD camera connected to a Pentium 4 personal computer. Placing the gel layers on the plane light source, transmittance images were detected by means of the CCD camera. A band-pass filter around 585 nm was moreover adopted only with Fricke gels. In fact, in Fricke gels ionising radiation gives rise to visible light absorption around 585 nm [12]. The CCD camera was Starlight Xpress SXL8-P (Starlight Xpress Ltd, Holyport, England), which is a low-noise camera with Peltier thermoelectric cooling, able to capture and digitise high-resolution images (12-bits depth). From the GL images of the dosimeters detected before and after irradiation, evaluation and graphical visualization of linear and planar dose distributions were obtained by means of dedicated software, developed in the laboratory. Details about the software are described elsewhere [4,13]. Sample exposures were always performed one day after gel dosimeter preparation.

2.3. Performed studies

2.3.1. Normoxic polymer gel dosimeter study

Three concentrations of the gelling agent were studied, namely 6%, 5% and 4% of the final weight. To this aim, normoxic polymer gels placed in cuvettes were homogeneously irradiated at different known doses, ranging from 2 Gy to 35 Gy. The dosimeters were then imaged 2 h after exposure and in the days after, up to 41 days. Light transmittance was as well measured by means of the spectrophotometer. Dose-sensitivity, dose-range of utilisation, reproducibility and temporal variation of the gel response after irradiation were investigated.

2.3.2. Depth dose measurements with normoxic- and Fricke gel dosimeters

Gel-layers have been inserted in a tissue-equivalent phantom and one by one exposed to a 18 MV Linac X-ray beam (Varian Clinac 2100c) with a source-surface distance of 100 cm and a field size of $3 \times 2\ cm^2$. The