Further developments and applications of layer gel dosimetry

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1. Introduction

The method used to perform dosimetry with Fricke-xylenol orange-infused gels in form of layers remains the most reliable method for in-phantom dose profiling and imaging in high fluxes of thermal and epithermal neutrons.

Gel-dosimeters in form of layers really give the possibility not only of obtaining spatial dose distributions but also of achieving measurements of each dose contribution in neutron fields. These advantages arise from the layer-geometry thanks to which neutron transport is not sensibly altered, even if the elemental gel composition is changed adding particular isotopes (for example 10B), as necessary to perform the separation of dose contributions.

The gel matrix composition and the experimental procedures, adopted for both dosimeter preparation and analysis, have been already described in previous works [1,2]. In the present work, the improvements of the method employed for gel analysis, dose imaging and gel applications are illustrated.

2. Methods and Results

The gel dosimeters used in the here reported experiments are rectangular or square layers three millimetres thick. The rectangular layers are 50 mm wide and 110 mm long, the square ones have 50 mm side. The gel composition is: Fricke solution (1 mM Fe(NH4)2(SO4)2 6H2O, 25 mM H2SO4), agarose (1% of the final weight C12H14O5(OH)4) as gelling agent and xylenol-orange (0.165 mM C31H27N2Na5O13S).

The gel layers are imaged through optical analysis; a CCD camera captures the visible light transmittance images of a gel layer placed on a plane light source, which instability in time is controlled and eventually amended by means of a grey-level (GL) strip. The absorbed dose is proportional to the optical density difference obtained from the logarithm of the ratio between the grey levels of the images before and after irradiation: Δ(OD) = log10(GLbefore / GLafter). To obviate the experimental uncertainty in the amounts of the chemical compounds used for preparing the dosimetry solution, some gel layers of each batch are always assigned to gamma calibration. Calibration allows to convert Δ(OD) images into dose images. The device dedicated to optical analysis of gel dosimeters is transportable and can be set up close to the reactor, in order to capture the images short time before and after gel exposure.
Dosimeters are prepared a few days before irradiations and stocked in a refrigerator; the temperature is kept at about 10°C, to avoid gel freezing and consequent irreparable damages.

A study has been carried out to optimise the waiting time between gel dosimeters irradiation and analysis for the adopted gel composition. Since a response variation in the first 30 minutes after irradiation had been already revealed, gel images at different dose values have been taken after 30, 40, 60, 80 minutes since irradiation. From the results, reported in figure 1, it is evident that gel sensitivity shows no more significant change after 30 minutes from irradiation. Finally a time of 40 minutes between irradiation and analysis has been chosen for the measurement protocol.

![Figure 1. Optical density change in time after irradiation.](image1)

![Figure 2. Gel sensitivity change after preparation.](image2)

Simultaneously, another study has been performed on gel response change with time after preparation in order to determinate the optimal time between preparation and irradiation. Hence some gel layers have been irradiated at different times after preparation: 3, 6, 24, 48 hours. In each case the images have been taken 40 minutes after irradiation. As shown in figure 2 the sensitivity of gel dosimeters does depend significantly on the time interval between preparation and irradiation if dosimeters are irradiated in the same day of their preparation, but becomes almost stable within 24 hours and they can be used for four or five days afterwards, eventually with very small sensitivity corrections.

The software dedicated to image elaboration has been implemented with MATLAB code: it operates all the necessary algorithms to obtain dose images from grey level images that were captured before and after irradiation. These algorithms allow also to amend spurious effect such as light-source instability in time. Moreover, the software is able to perform separation of dose contributions in thermal and epithermal neutron fields, where gamma dose and charged particle dose is always present. The γ-dose arises from \(^1\text{H}(n,\gamma)^2\text{H}\) thermal neutron reaction on the hydrogen nuclei in the T.E. phantom and from background; another dose contribution comes from protons due to \(^{14}\text{N}(n,p)^{14}\text{C}\) reaction and from the recoils of hydrogen nuclei constituting the main contribution due to the fast component of the beam. If gel dosimetry is dedicated to boron neutron capture therapy (BNCT) [3,4] the “therapeutic dose” comes from \(\alpha\) and \(^7\text{Li}\) particles emitted in the \(^{10}\text{B}(n,\alpha)^{7}\text{Li}\) thermal neutron reaction.

The software is able to visualize how the dose varies in all the gel layer plane. In figure 3a, an example of dose representation is reported.

Within a research project dedicated to BNCT experimentation, absorbed dose profiles with gel layers have been measured, in phantom and in free beam. Exposures have been carried out in the thermal and epithermal column of the RVS-TAPIRO reactor at the ENEA Casaccia Research Centre (Rome).
The exposures in thermal column had the aim of investigating the gel dosimeter sensitivity to thermal neutrons. Gel dosimeter sensitivity depends on radiation LET; as in the most part of dosimeters, sensitivity decreases with LET increasing. Since BNCT procedures involve charged particles of various LET, some measurements have been done to determine the dosimeter sensitivity to α-particles and ⁷Li ions emitted in the ¹⁰B reaction. Gel dosimeter sensitivity, relative to gamma sensitivity, has resulted to be in the range 0.40–0.45. The value 0.42 has been adopted for dose separation algorithms. Regarding the sensitivity to protons, no measurement has been performed but values found in literature have been utilized [5].

In the epithermal column, measurements were aimed to study dose distributions in presence of the proper amount of ¹⁰B accumulations, that is usually at 35 or 40 ppm in tumours and at 10 ppm in healthy tissue. In such configurations, the dose contributions to be discriminated are the γ-dose, the proton dose, the therapeutic dose and the fast neutron dose. The absorbed dose distributions have been measured in the central plane of a cylindrical polyethylene phantom 16 cm in diameter, 14 cm high. During all exposures, the phantom has been placed facing the collimator, with the cylinder axis fitting the neutron beam axis. In figure 3b, the phantom laying on the support for irradiation in the epithermal column is shown: the gel layers are inserted in the central plane. The reliability of the results has been always tested by comparison with the results obtained by means of thermoluminescence dosimeters and activation foils. In figure 4a, all the depth dose profiles in the central axis of the phantom, extracted from dose images, are reported. Since the nitrogen an fast neutron doses are scarcely visible in the figure, but their determination is very important owing to their high biological efficacy, such two dose components are reported separately in a proper scale in figure 4b.
3. Conclusion

The consistency of all results is a confirmation of the validity of the proposed methods for absorbed dose separation by means of Fricke-xylenol-orange-infused layered gels.

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References

[1] Gambarini G, Mariani M, Pirola L, Pompilio E, Prestini P, Sella M and Tomatis S 2001 Characterization of a portable system for dose imaging in Fricke-xylenol-orange-gels *Proc. 2nd Int. Conf. on Radiotherapy Gel Dosimetry (Brisbane, Australia)* pp 157–9

[2] Gambarini G, Birattari C, Mariani M, Marchesini R, Pirola L, Prestini P, Sella M and Tomatis S 2004 Study of light transmittance from layers of Fricke-xylenol-orange-gel dosimeters having different composition and analysed with various modalities *Nucl. Instrum. Meth. B* 213 321–4

[3] Gambarini G, Birattari C, Colombi C, Pirola L and Rosi G 2002 Fricke-gel dosimetry in boron neutron capture therapy *Radiat. Prot. Dosim.* 101 419–22

[4] Gambarini G 2001 Gel dosimetry in neutron capture therapy *Proc. 2nd Int. Conf. on Radiotherapy Gel Dosimetry (Brisbane, Australia)* pp 89–91

[5] Bäck S Å J, Medin J, Magnusson P, Olsson P, Grusell E and Olsson L E 1999 Ferrous sulphate gel dosimetry and MRI for proton beam dose measurements *Phys. Med. Biol.* 44 1983–96.