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Gamma/neutron dose evaluation using Fricke gel and alanine gel dosimeters to be applied in boron neutron capture therapy

T.F. Mangueira *, C.F. Silva, P.R.P. Coelho, L.L. Campos

Instituto de Pesquisas Energéticas e Nucleares (IPEN-CNEN), Comissão Nacional de Energia Nuclear, Av. Prof. Lineu Prestes, 2242, 05508-000 São Paulo, SP, Brazil

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ABSTRACT

Gel dosimetry has been studied mainly for medical applications. The radiation induced ferric ions concentration can be measured by different techniques to be related with the absorbed dose. Aiming to assess gamma/thermal neutrons dose from research reactors, Fricke gel and alanine gel solutions produced at IPEN using 300 bloom gelatin were mixed with $Na_2B_4O_7$ salt, and the mixtures were irradiated at the beam hole #3 of the IEA-R1 research reactor, (BH#3) adapted to BNCT studies, and the dose-response was evaluated using spectrophotometry technique.

1. Introduction

Radiosurgery is a non-invasive surgery technique carried out through the release of directed ionizing radiation beams. This technique is commonly applied in complex head and neck tumors and, depending on the intensity of the seriousness, in a few types of thorax and abdomen treatments. This procedure was developed because conventional surgical treatment cannot be applied in many diseases, due to technical difficulties or to the risk of vital structures damage (Gambarini et al., 2002). The intent of radiotherapy is to achieve a significant dose absorption in the tumor, with low dose deposition in the surrounding healthy tissues (Gambarini et al., 1997).

Neutron radiation from nuclear reactors is used in a type of radiosurgery for the treatment of brain tumors called boron neutron capture therapy (BNCT) that depends on the interaction of thermal neutrons with ^{10}B isotope injected in the tumor to produce alpha particles (Barth et al., 1996).

Due to the boron nuclei accumulated in cancerous tissue by a tumor-specific carrier agent and the high cross section ($\sigma = 3840.10^{-28}\,m^2$) of thermal neutrons for the reaction $^{10}B(n,\alpha)^7Li$, this technique increases the relation tumor/healthy tissue dose. Besides this fact, the spatial dose absorption distribution is mandatory to the treatment planning (Gambarini et al., 2002).

One technique to determine the dose distribution on a volume is gel dosimetry. Its first contemporary paper was published by Gore et al. (1984). The dosimetric systems are based on quantifying the radiation induced transformation of ferrous ions (Fe^{2+}) in ferric ions (Fe^{3+}). Nowadays, this kind of radiation dosimetry has been improved by many gel types and applications in radiotherapy techniques with photons, such as intensity-modulated radiotherapy and stereotactic radiosurgery, besides proton beams, high-energy carbon ion beams and epithermal neutron beams therapies; (Uusi-Simola et al., 2007) in other words, gel dosimetry has been principally researched to be applied to check complex cancer treatment planning (Gambarini et al., 1997).

Aiming to assess the gamma/thermal neutron doses in the mixed gamma-neutron field from the IPEN nuclear research reactor IEA-R1 using the beam hole adapted to BNCT studies (named BH#3) (Fig. 1) both studied dosimetric systems, namely, Fricke xylenol gel (FG) and alanine xylenol gel (AG) solutions developed at IPEN, were prepared using 300 Bloom porcine skin gelatin as gelling agent. In the present study, sodium tetraborate salt ($Na_2B_4O_7$) containing 19.9% of ^{10}B isotope was added to the gel solutions to improve the thermal neutron dose response. At this stage of the study, the measurements were carried out using the spectrophotometry technique; however, it is intended to obtain magnetic resonance images and three-dimensional (3D) dose distributions in the future.

2. Materials and methods

The dosimetric solutions were prepared with three-distilled water at room atmosphere and temperature according to the methods described by Olsson et al. (1989) and Cavinato and Campos (2007) to FG solutions and Mizuno (2007) to AG solutions using 300 Bloom gelatin. The chemical compositions of the studied solutions are presented by Table 1.

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* Corresponding author. Tel./fax: +55 11 3133 9671.
E-mail address: lcrodri@ipen.br (T.F. Mangueira).

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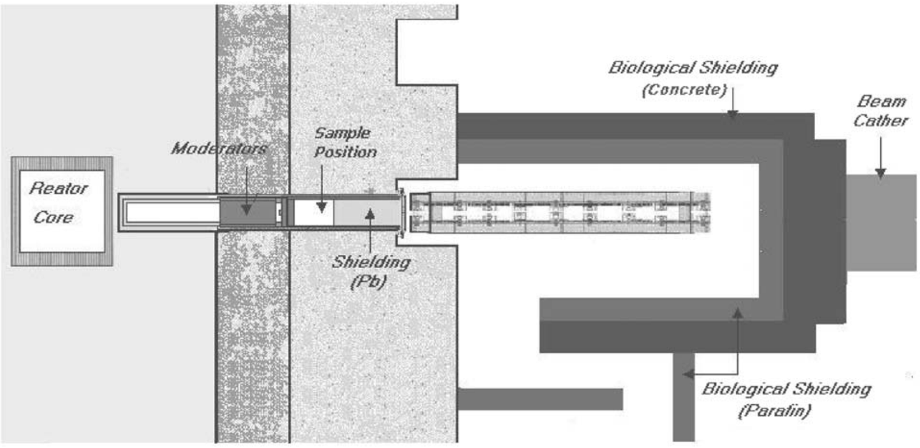

Fig. 1. Sketch of the BH#3 with sample support inserted (horizontal section).

Table 1
Chemical composition of dosimetric gel solutions.

Compound	C (mol/L)	
	Fricke gel	**Alanine gel**
Ferrous ammonium sulfate	0.001	0.001
Sodium chloride	0.001	–
Xylenol	0.0001	0.0002
Sulfuric acid	5.00×10^{-02}	0.2375
DL-alanine	–	0.6735
Sodium tetraborate[a]	60 ppm	
Gelatin (300 Bloom)	10% of the three-distilled water volume	

[a] Containing 19.9% of ^{10}B isotope.

The measurement technique is based on the quantification of radiation induced transformation of ferrous ions (Fe^{2+}) present in the solution in ferric ions (Fe^{3+}). The ferric ions concentration can be measured through the spectrophotometry technique by comparing the wavelengths of 457 nm band that corresponds to ferrous ions concentration, and 585 nm band that corresponds to ferric ions concentration.

The absorbed dose is given by (Fricke and Hart, 1955)

$$D=\frac{N_A\cdot e}{\rho\cdot l\cdot G(Fe^{3+})}\frac{OD(D)-OD(0)}{\varepsilon_m} \tag{1}$$

where D is the absorbed dose, $G(Fe^{3+})$ is the chemical yield of Fe^{3+} (expressed in ions produced per 100 eV), ρ is the density expressed in kg/L, N_A is Avogadro's number, e is the conversion factor from Joules to electron volt, l is the optical path length (width of the cuvette holding the solution), $OD(D)$ and $OD(0)$ are the optical densities at 585 nm of the irradiated and unirradiated dosimeter, respectively, and ε_m is the molar extinction coefficient for Fe^{3+}.

It is clear from Eq. (1) that the absorbed dose is proportional to the variation on the optical densities, considering that the other terms are constants, in such a way that it is more practical to use a calibration curve to determine an unknown dose received by a dosimeter from the same calibrated batch than determine the chemical yield $G(Fe^{3+})$ for each batch (Schreiner, 2004).

Both gels were prepared 12 h before irradiation and the dosimeters were maintained at 6 °C for gel solidification and oxidation rate of ferrous ions reduction. One hour before irradiation, the dosimeters were removed from refrigerator to stabilize at room temperature ($\sim$20 °C).

The dosimeters were irradiated in mixed gamma/thermal neutron beam at BH#3 of the IEA-R1 research reactor and in air and electronic equilibrium at the ^{60}Co gamma source (GammaCell) of the Radiation Technology Center–CTR, both belonging to IPEN. The gamma and thermal neutrons absorbed doses at BH#3 were determined using LiF Albedo dosimeters.

The FG and AG dose response curves to ^{60}Co gamma radiation were obtained by irradiating the dosimeters prepared with and without the addition of $Na_2B_4O_7$ to the solution with different doses between 0.85 and 15 Gy.

The BH#3 beam is essentially composed by gamma and thermal neutron radiation; the dose rates are about 0.34 Gy/min for neutrons and 0.085 Gy/min for gamma radiation and vary in up to 1% due to the fact that the reactor is weekly started up and shut down.

The dose response curves for samples prepared with and without the addition of $Na_2B_4O_7$ irradiated at the BH#3 with mixed radiation field were obtained by irradiating the dosimeters in the gamma+neutron dose range between 3.4 and 51 Gy, according to Albedo dosimeters evaluation.

3. Results and discussion

The dose response curves of FG and AG solutions prepared with and without ^{10}B addition to ^{60}Co gamma radiation are shown in Fig. 2a and b. The dosimeters were irradiated at GammaCell source with absorbed doses of 0.850, 1.70, 2.55, 3.40, 5.00, 10.0 and 15.0 Gy.

The optical response presents a linear behavior in the studied dose range. The FG solution presents a response that is 1.18 times the response of AG solution. FG solution with ^{10}B addition presents a response that is 1.31 times the response of AG solution with ^{10}B addition. The ^{10}B addition increases the FG solution sensitivity.

The dose response curves of FG and AG dosimeters irradiated in BH#3 are seen in Fig. 3. The dosimeters were exposed during 10, 20, 30, 40, 60 and 120 min. The transit time (insertion plus take off time) of a sample is about 1 min, being more significant to minor exposition times (see Fig. 3 and 4).

The difference between the signal obtained in the mixed field irradiation (BH#3) and in the ^{60}Co gamma field irradiation is the signal that corresponds to the dose delivered to the solutions by thermal neutrons radiation. With this data, the dose response curves were plotted for thermal neutrons dose as seen on Fig. 4.

According to the results obtained for the irradiations carried out at IAEA-R1 Nuclear Reactor, the thermal neutron doses higher than 6 Gy can be evaluated and the FG/AG response ratio is equal to 1.57.

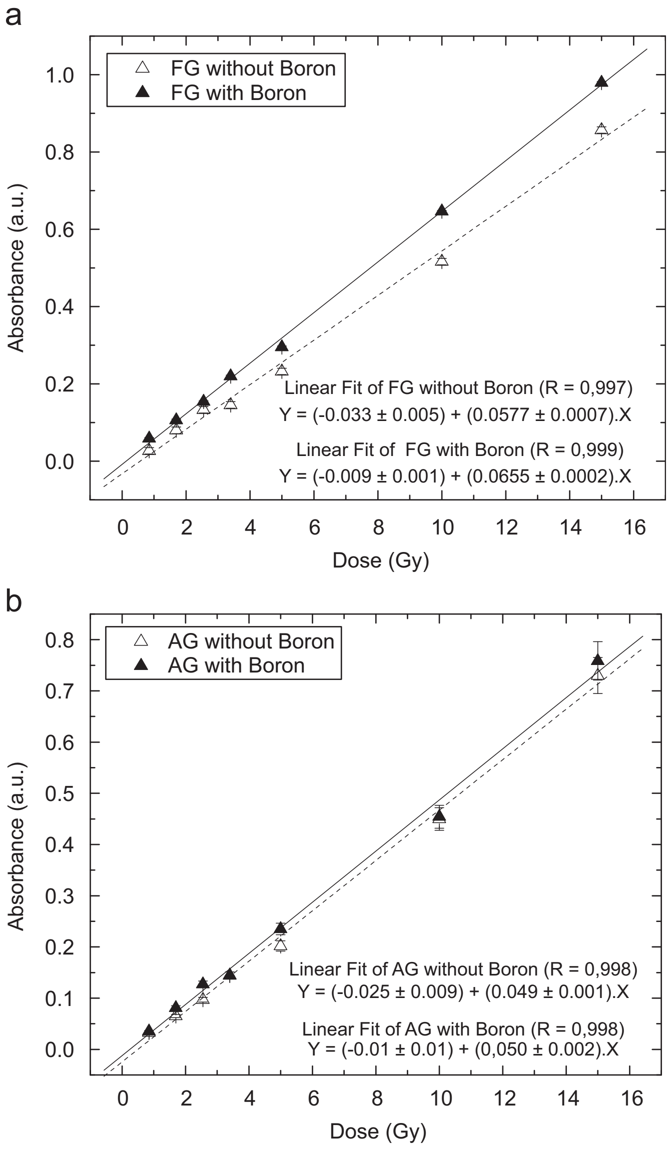

Fig. 2. (a) FG with and without ^{10}B addition dose response curves to ^{60}Co gamma radiation. (b) AG with and without ^{10}B addition dose response curves to ^{60}Co gamma radiation.

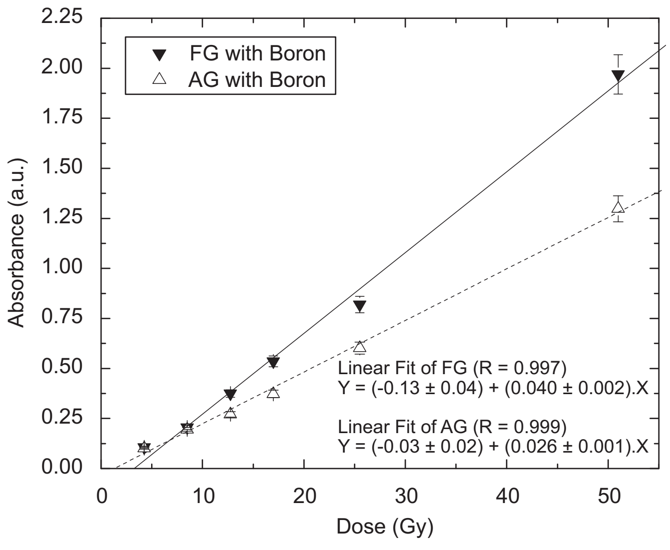

Fig. 3. FG and AG with and without ^{10}B addition dose response curves to gamma/ neutron radiation.

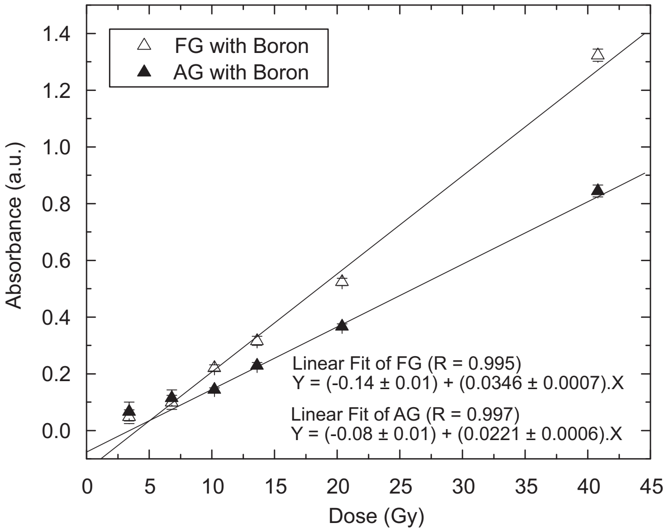

Fig. 4. FG and AG with ^{10}B addition dose response curves to thermal neutrons only.

The addition of sodium tetraborate improves the response of both FG and AG dosimeters for thermal neutrons, mainly the FG response.

4. Conclusions

The optical dose response to ^{60}Co gamma radiation of FG solutions prepared with ^{10}B addition increases compared to the optical dose response of FG solutions prepared without ^{10}B addition.

FG solutions are more sensitive than AG solutions with and without ^{10}B addition.

Both FG and AG solutions mixed with sodium tetraborate can be a good choice to evaluate the gamma and neutron doses in BNCT procedures. Further measurements to evaluate the high-LET effect and the dose distribution in a special phantom for the magnetic resonance image technique will improve this method.

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