Gamma/Neutron Dose Evaluation Using Fricke Gel and Alanine Gel Dosimeters to be Applied in Boron Neutron Capture Therapy

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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 and related with the absorbed dose. Aiming the assessment of gamma/thermal neutrons dose from research reactors the Fricke Gel and Alanine Gel solutions produced at IPEN using gelatin 300 bloom were mixed with $Na_2B_4O_7$ salt, irradiated at the Beam Hole #3 of the IEA-R1 research reactor (BH#3) adapted to BNCT studies, and the dose-response evaluated using spectrophotometry technique.

Keywords: Fricke Gel; Alanine Gel; Boron Neutron capture Therapy (BNCT).

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INTRODUCTION

Radiosurgery is a non-invasive surgery carried out by means of directed beams of ionizing radiation. This technique is used to be applied in complex tumors treatment in head and neck, and in few kind of treatment in thorax and abdomen, it depending on the intensity of the seriousness. This procedure was developed since there are many diseases for which conventional surgical treatment can not be applied, due to difficult or vital structures being damaged (Gambarini, 2002). The intent of radiotherapy is the achievement of a significant dose absorption in tumor, with low dose deposition in surrounding healthy tissues (Gambarini, 1997).

Neutron radiation from nuclear reactors is used in a kind of radiosurgery called Boron Neutron Capture Therapy (BNCT) for the treatment of brain tumors which depends on the interaction of slow neutrons with ^{10}B isotope injected in the tumor to produce alpha particles.

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

One way to determine the dose distribution on a volume is Gel Dosimetry. The current Gel Dosimetry presented the first published work in 1984 by Gore et al. The dosimetric systems is based on quantify the radiation induced transformation of ferrous ions (Fe^{2+}) in ferric ions (Fe^{3+}). Nowadays this kind of radiation dosimetry has been enhancement to many types of gel and applications in radiotherapy techniques such as intensity-modulated radiotherapy or stereotactic radiosurgery besides with proton beams, highenergy carbon ion beams and epithermal neutron beams therapies (Uusi-Simola, 2007), in other words, it has being principle researched to be applied in complex cancer treatment plan checking (Gambarini et al, 1997).

Aiming to assess the gamma/thermal neutron doses in mixed gamma-neutron field from the IPEN nuclear research reactor IEA-R1 using the beam hole adapted to BNCT studies (named BH#3) both studied systems (Fig.1), Fricke Xylenol Gel (FG) and Alanine Xylenol Gel (AG) solutions developed at IPEN, prepared using as gelling agent 300 Bloom porcine skin gelatin were evaluated. In this study sodium tetraborate salt ($Na_2B_4O_7$) containing 19.9% of ^{10}B isotope was added to the gel solutions with the purpose of improving the thermal neutron dose response. The measuring technique in this stage was spectrophotometry with the purpose in the future to obtain Magnetic Resonance Images and three-dimensional (3D) dose distribution.

Figure 1 - Sketch of the BH#3 with sample support inserted (horizontal section)

MATERIALS AND METHODS

The dosimetric solutions were prepared utilizing three-distilled water at room atmosphere and temperature using the method described by Bero 2001 and Cavinato 2007 to FG solutions and Mizuno 2007 to AG solutions using gelatin (300 Bloom). Theses gels are conditioned into standard spectrophometric cuvettes (1 x 1 x 4.5 10^{-6} m^3 and 10^{-2} m of optical length). The chemical composition of the studied solutions is presented at table 1.

The measure 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 by spectrophotometry technique comparing the wavelength at 585 nm band that corresponds to ferric ions concentration.

The optical densities at 585 nm band before (OD(D)) and after (OD(0)) irradiation were measurements using a spectrophometer Shimadzu UV-2101PC.

The absorbed dose is given by (Fricke, 1955):

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

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 in kg/L, N_A is Avogadro's number, e is the number of Joules per electron volt, l is the optical path length (width of the cuvette holding the solution), and ε_m is the molar extinction coefficient for Fe^{3+}.

From equation (1) it is clear that the absorbed dose is proportional to the variation on the optical densities, considering that the other terms are constants. By this way is more practice use a calibration curve to determine a unknowing dose at a dosimeter from the same batch than determine the chemical yield $G(Fe^{3+})$ to each batch (Schreiner, 2004).

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

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 ^{60}Co gamma source

(GammaCell) of the Radiation Technology Center - CTR both of IPEN. The gamma and thermal neutrons absorbed doses at BH#3 were determined using LiF Albedo dosimeters.

On BH#3 the cuvettes were positioned in such way that the center of optical face agrees with the geometrical center of the beam and the longitudinal axe of the cuvettes is perpendicular to the geometrical center of beam.

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

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. The dose rates vary up to 1% due to on/off reactor, which occurs weekly.

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

RESULTS AND DISCUSSION

The dose response curves of FG and AG dosimeters to ^{60}Co gamma radiation is shown on (Fig. 2a) and (Fig. 2b). The dosimeters were irradiated at GammaCell source with doses of 0.850, 1.70, 2.55, 3.40, 5.00 10.0 and 15.0 Gy.

Figure 2a and 2b –Dose response curves for gamma irradiated FG and AG solutions with and without ^{10}B addition.

The optical response presents linear behavior in dose range studied. The FG solution presents the sensitivity 18 % higher than AG solution. FG solution with ^{10}B addition presents the sensitivity 31 % more than AG solution.

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

Figure 3- Gamma/Neutron dose response curves of FG and AG solutions with ^{10}B addition.

The difference between the mixed field signal (BH#3) and the gamma irradiation signal (CTR) is the thermal neutron radiation signal. With this information the dose response curves were plotted for thermal neutron dose as seen on Fig. 4.

Figure 4- Dose response curves for thermal neutrons of FG and AG solutions with ^{10}B addition.

According to the obtained results to irradiations carried out at IAEA-R1 Nuclear Reactor, the neutron doses evaluated achieve FG sensitivity 57 % superior to AG.

The addition of sodium tetraborate increases the response of both FG and AG, but only FG sensitivity.

CONCLUSIONS

The two dosimetric systems had there optical response changed with the addition of sodium tetraborate. However, the only system that had its sensitivity altered was the FG. These alterations do not invalidate the dosimetric system results, and they can be a good choice to evaluate the gamma and neutron doses in BNCT procedures. Further measurements to evalute the high-LET effect and dose distribution in a phantom used in the Magnetic Resonance Image technique will improve this method.

The obtained results indicate that the FG and AG solutions mixed with sodium tetraborate developed at IPEN can be used to determine the dose distribution in gamma-neutron fields

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Figure captions:

Figure 1 - Sketch of the BH#3 with sample support inserted (horizontal section)

Figure 2a- Dose response curves for gamma irradiated FG solutions with and without ^{10}B addition.

Figure 2b- Dose response curves for gamma irradiated AG solutions with and without ^{10}B addition.

Figure 3- Gamma/Neutron dose response curves of FG and AG solutions with ^{10}B addition.

Figure 4- Dose response curves for thermal neutrons of FG and AG solutions with ^{10}B addition.

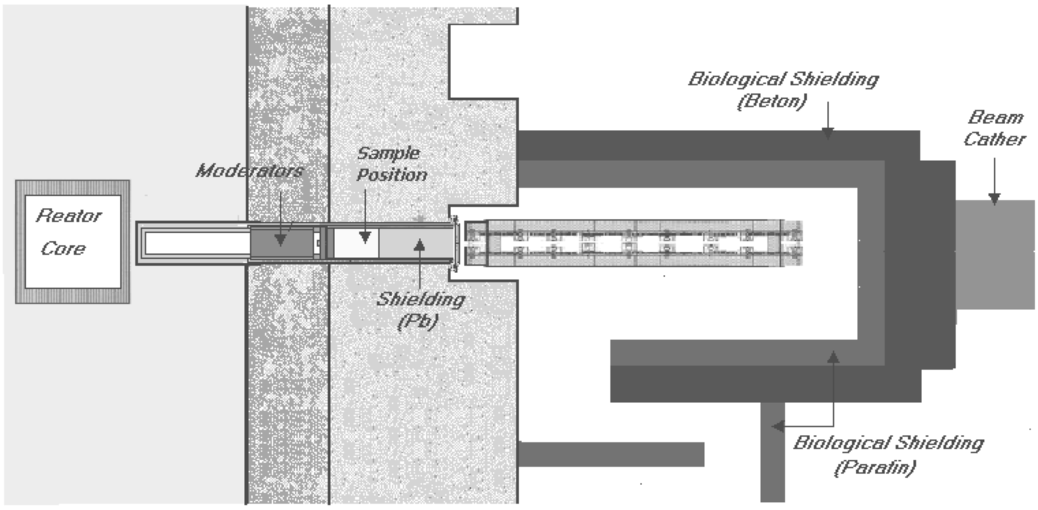
Biological Shielding
(Beton)
Beam
Cather
Sample
Position
Moderators
Reator
Core
Shielding
(Pb)
Biological Shielding
(Parafin)

Fig. 1

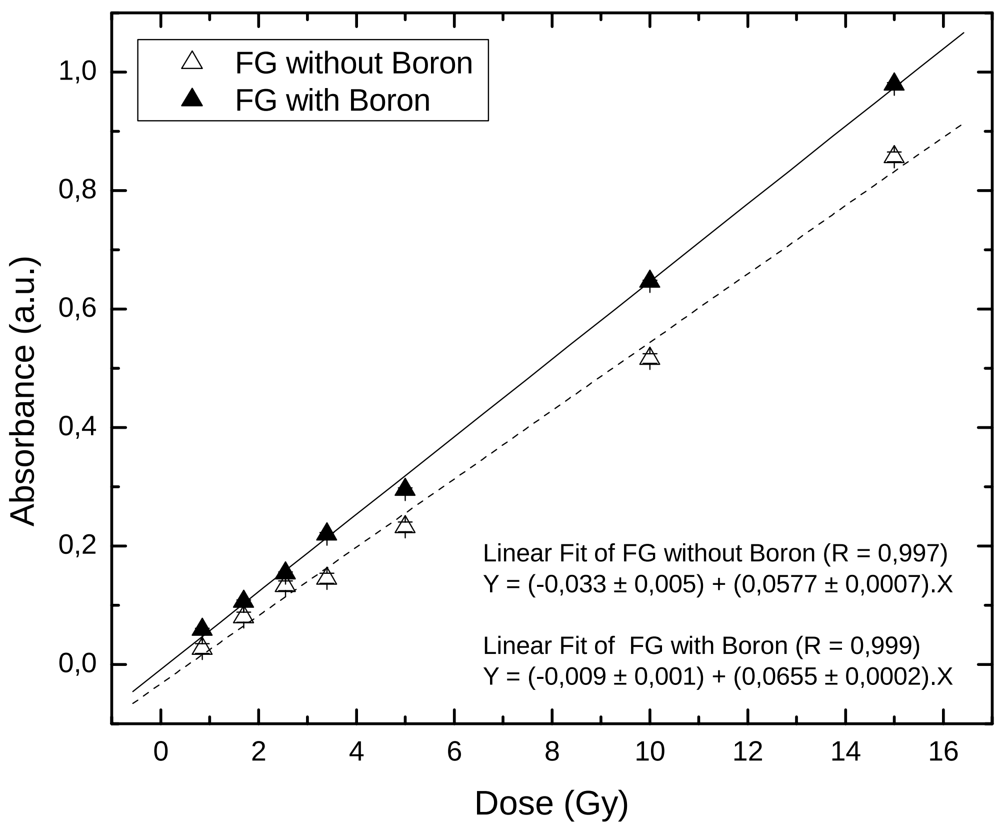
FG without Boron
FG with Boron
Linear Fit of FG without Boron (R = 0,997)
Y = (-0,033 ± 0,005) + (0,0577 ± 0,0007).X
Linear Fit of FG with Boron (R = 0,999)
Y = (-0,009 ± 0,001) + (0,0655 ± 0,0002).X
Absorbance (a.u.)
Dose (Gy)
0,0
0,2
0,4
0,6
0,8
1,0
0
2
4
6
8
10
12
14
16

Fig. 2a

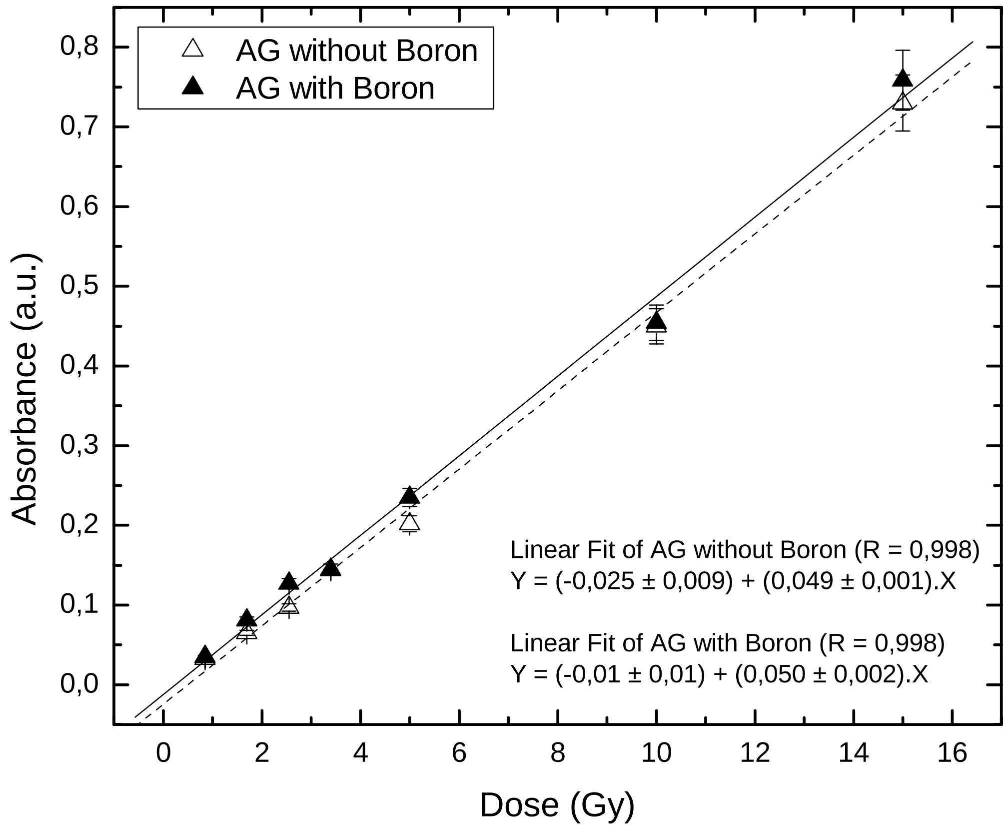
AG without Boron
AG with Boron
Linear Fit of AG without Boron (R = 0,998)
Y = (-0,025 ± 0,009) + (0,049 ± 0,001).X
Linear Fit of AG with Boron (R = 0,998)
Y = (-0,01 ± 0,01) + (0,050 ± 0,002).X
Absorbance (a.u.)
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
Dose (Gy)
0
2
4
6
8
10
12
14
16

Fig. 2b

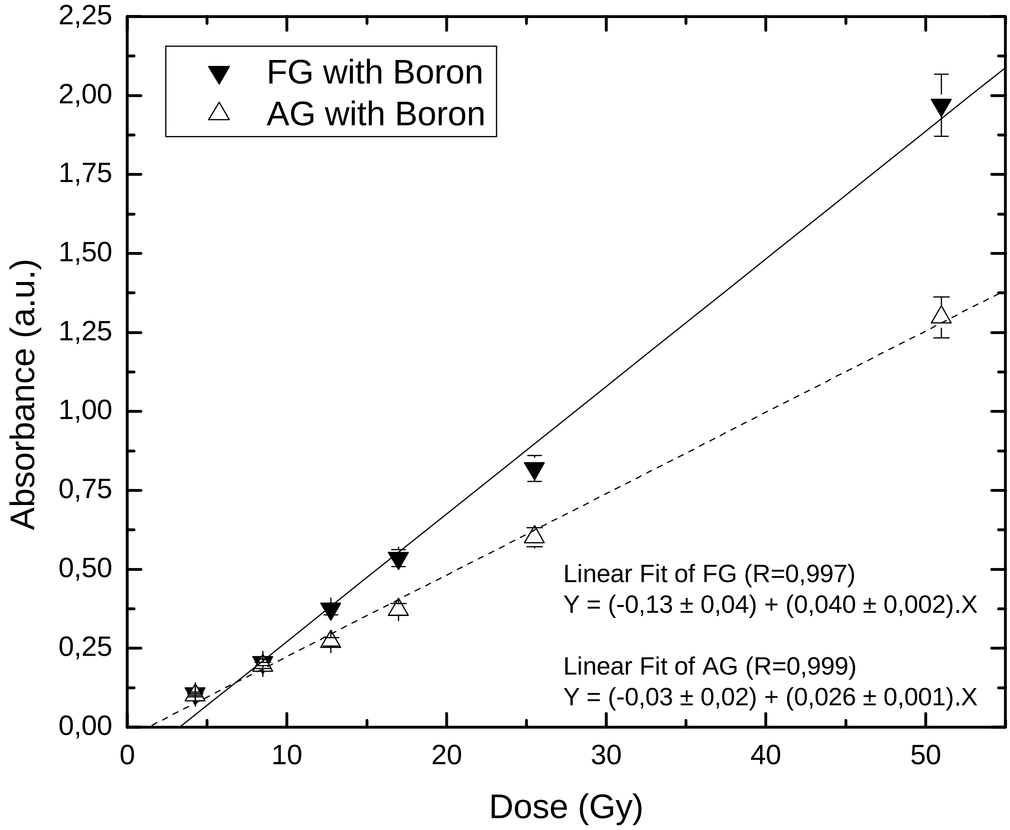
FG with Boron
AG with Boron
Absorbance (a.u.)
Dose (Gy)
Linear Fit of FG (R=0,997)
Y = (-0,13 ± 0,04) + (0,040 ± 0,002).X
Linear Fit of AG (R=0,999)
Y = (-0,03 ± 0,02) + (0,026 ± 0,001).X
2,25
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25
0,00
0
10
20
30
40
50

Fig. 3

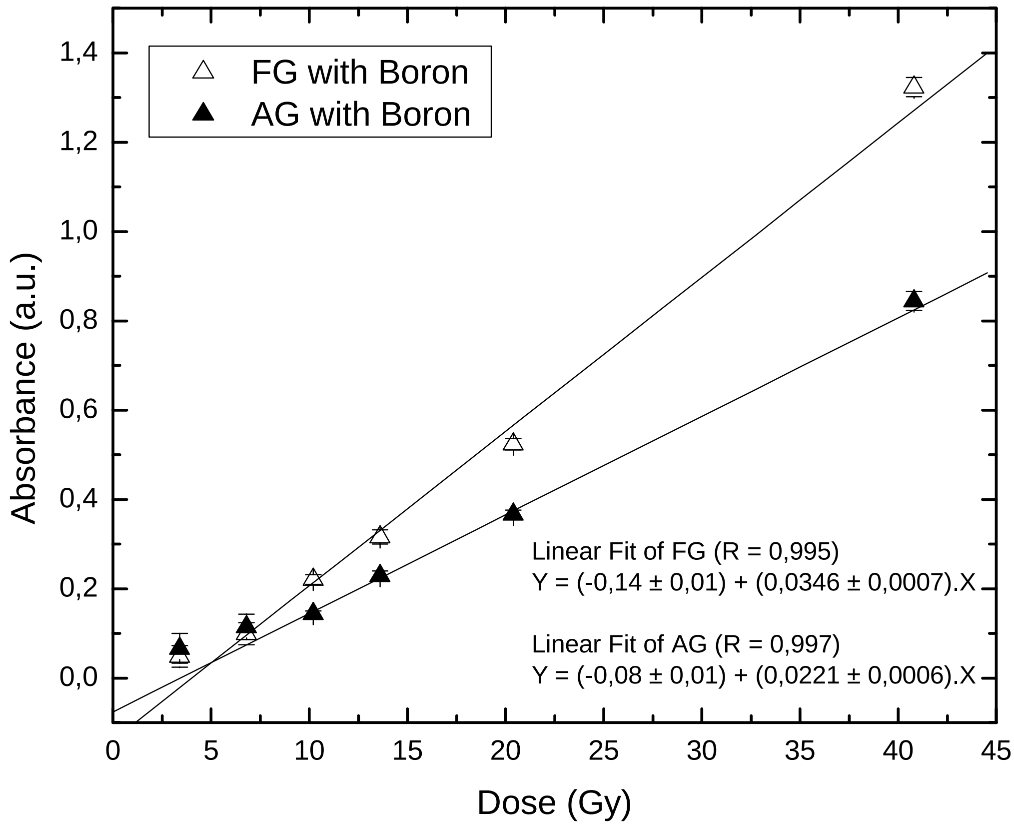
FG with Boron
AG with Boron
Linear Fit of FG (R = 0,995)
Y = (-0,14 ± 0,01) + (0,0346 ± 0,0007).X
Linear Fit of AG (R = 0,997)
Y = (-0,08 ± 0,01) + (0,0221 ± 0,0006).X
Absorbance (a.u.)
Dose (Gy)
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
0
5
10
15
20
25
30
35
40
45

Fig. 4

Table 1: Chemical composition of Dosimetric gel solutions

	C (mol/L)	
Compound	**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†	$3{,}5\ 10^{-3}$ (60 ppm ^{10}B)	
Three-distilled water	5,55	
Gelatin (300 Bloom)	10 % of the three- distilled water mass	

† containing 19.9% of ^{10}B isotope.