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Measurement and modeling of the effect of gamma irradiation on radiofrequency dielectric properties of bovine kidney tissue

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The effect of gamma irradiation on the radiofrequency dielectric properties of bovine kidney tissue has been investigated using gamma irradiator (Gs 1000), booton (7200) capacitance meter, signal generator (Lodstars SG-416013) and Dielectric cells Mathematic models of the following dielectric structural parameter, Dielectric spread parameter (α), dielectric decrement (Δ) and Dielectric relaxation time (τ), were also developed. The mathematics models were found to be polynomial functions of degree 4,4, and 5 respectively. The coefficient of fit for dielectric decrement, relaxation time and spread parameter (α), were found to be 98.2, 83.9 and 99.5, respectively. This shows that, the mathematical model can be effectively used to generate dielectric data that will facilitate the prediction of the extent of mammalian kidney tissue damage in gamma irradiation doses regime usually encountered in diagnostic and therapeutic radiology.

Key word: Gamma irradiation, spread parameter (α), dielectric decrement (Δ), dielectric relaxation time (τ), dielectric permittivity (ε').

INTRODUCTION

The dielectric methods of investigating structural and molecular characteristics of biological tissues is a well established techniques (Essex et al., 1975; Kyber et al., 1991; and Laogun et al., 2005). They have been frequently used to study changes in material composition, cell structure and water content under certain physical conditions (Laogun, 1986). The common feature of all these methods is that, the biological sample is contained in a sample holder and its complex permittivity is measured at various discrete frequency points (Burdette et al., 1980; Grant et al., 1978). Alterations or change induced to biological tissues is as a result of the its interaction with ionizing radiation can be measured or inferred from βeta-dielectric dispersion properties of the irradiated tissues. These studies are prompted by the pride of place given to the use of ionizing radiation in diagnostic and therapeutic applications in healthcare and the need to established safety radiation levels (Laogun et al., 2005; and Agba et al., 2008).

Mathematical models of biological tissues provides

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Table 1. The mean a.c conductivity of γ-irradiated and non-irradiated bovine kidney from frequency range 0.5 to 50.0 MHz.

Frequency (MHZ) / Dose (Gy)	Conductivity (σ) 0.5	1.0	2.0	5.0	10	20	30	40	50
0	212.1 ± 34.2	219.0 ± 29.6	220.8 ± 40.2	262.9 ± 20.1	357.5 ± 56.6	432.6 ± 12.5	529.1 ± 18.6	652.1 ± 14.7	673.1 ± 28.9
1	259.4 ± 21.3	274.4 ± 18.6	274.4 ± 11.6	297.2 ± 23.0	402.1 ± 21.2	498.9 ± 25.5	566.8 ± 44.1	672.6 ± 68.2	682.8 ± 56.2
4	355.9 ± 30.2	359.8 ± 24.6	369.5 ± 37.8	370.3 ± 44.2	468.3 ± 25.3	587.7 ± 55.4	613.5 ± 40.7	695.0 ± 33.3	735.7 ± 21.1
11	366.3 ± 41.8	375.2 ± 64.2	395.3 ± 48.2	396.1 ± 76.4	466.3 ± 34.3	662.6 ± 42.1	675.7 ± 29.8	732.7 ± 45.6	746.3 ± 40.0
20	482.0 ± 16.3	505.1 ± 49.8	521.4 ± 53.0	531.9 ± 51.5	569.9 ± 34.8	675.7 ± 37.3	680.3 ± 47.2	746.7 ± 18.8	766.6 ± 46.2
43	519.5 ± 58.2	519.5 ± 41.6	537.6 ± 33.7	578.1 ± 46.3	579.7 ± 11.3	678.0 ± 38.2	712.0 ± 49.3	746.7 ± 41.5	781.5 ± 23.4
60	584.8 ± 60.1	598.9 ± 46.4	600.8 ± 21.8	602.6 ± 44.5	647.3 ± 29.4	690.0 ± 63.1	709.3 ± 28.4	746.9 ± 19.6	785.8 ± 13.4
85	614.1 ± 21.8	630.9 ± 29.7	658.9 ± 40.3	685.0 ± 53.0	699.3 ± 29.3	717.1 ± 38.7	746.9 ± 74.2	759.2 ± 53.4	794.9 ± 36.4

reasonable mathematical approximation of the physco-chemical changes occurring in a biological systems and is calibrated against real data obtained from experimental investigations. Effect of Ionizing radiations on human health has been reported by researchers such as Pethig (1991), AAMP (1992), UNSCEAR (1993), Roger (2006) and Russel and Bradley (2007). This study is aimed at modeling the effect of gamma irradiation on Bovine tissue at radiofrequency so as to predict its effects on mammalian tissues at doses within the diagnostic and therapeutic dose regime often encountered in radiology.

METHODOLOGY

The kidney tissue samples were excised from certified freshly slaughtered adult cow at Gwagwalada Central Abattoir in Gwagwalada Area Council Abuja, Nigeria. The excised tissue samples were washed with double distilled water and preserved in laboratory oven maintained at a temperature of 37± 0.5°C for 6 h so as to remove water from its surface. The samples were sealed and labeled in eight (8) plastic film bags. They were irradiated while the sample holders were positioned along their length at the centre of the irradiation field with irradiation doses: 0 Gy, 1 Gy, 4 Gy,11 Gy, 20 Gy,43 Gy, 60 Gy and 85 Gy, respectively.

The sample cells used in this research were constructed and calibrated in line with the method of Laogun et al. (2005) and Agba et al. (2008). The gamma irradiator (GS 1000) located at the Gamma irradiation facility (GIF) unit of National Nuclear Technology Centre, Abuja was used for the irradiation of the bovine kidney tissue samples at the dose rate of 0.36 kGy/h. Dielectric measurements were carried out using boonton (7200) capacitance meter in conjuction with signal generators (Lodstar, SG-416013 and Harris, G857993). The effective capacitance ΔC and dissipation factor (tanδ) of the gamma irradiated kidey tissue samples were first measured after which the dielectric permittivity (ε") and dielectric conductivity (σ) were obtained using the equations below:

$$\Delta C = k\varepsilon' \tag{1}$$

$$\varepsilon'' = \varepsilon' \tan\delta \tag{2}$$

$$\sigma = 2\pi f \varepsilon_0 \varepsilon'' \tag{3}$$

Where, ε_0 = permittivity of free space, k = cell costant, ΔC = Effective capacitance, ε'' = Dielectric loss factor, σ = Dielectric coductivity values measured at limiting frequency and static frequency.

The dielectric relaxation time and the dielectric spread parameter α were evaluated using the frequency of the peak values of dielectric loss-factors for each dose and the cole-cole plots of dielectric loss factor (ε'') versus dielectric permittivity (ε') respectively. All measurement were carried out at the temperature of 28.0 ± 0.5°C and radiofrequency range of 0.5 to 50 MHz. The dielectric structure parameters were then modeled using computer aided curve fitting procedure.

RESULTS AND DISCUSSION

The dielectric conductivity (α), of the γ-irradiated bovine kidney tissue samples was found to be larger than that of the non-irradiated kidney tissue. The result also revealed that the dieletric conductivity increased with increase in gamma irradiation doses as in Table 1 and Figure 1. This

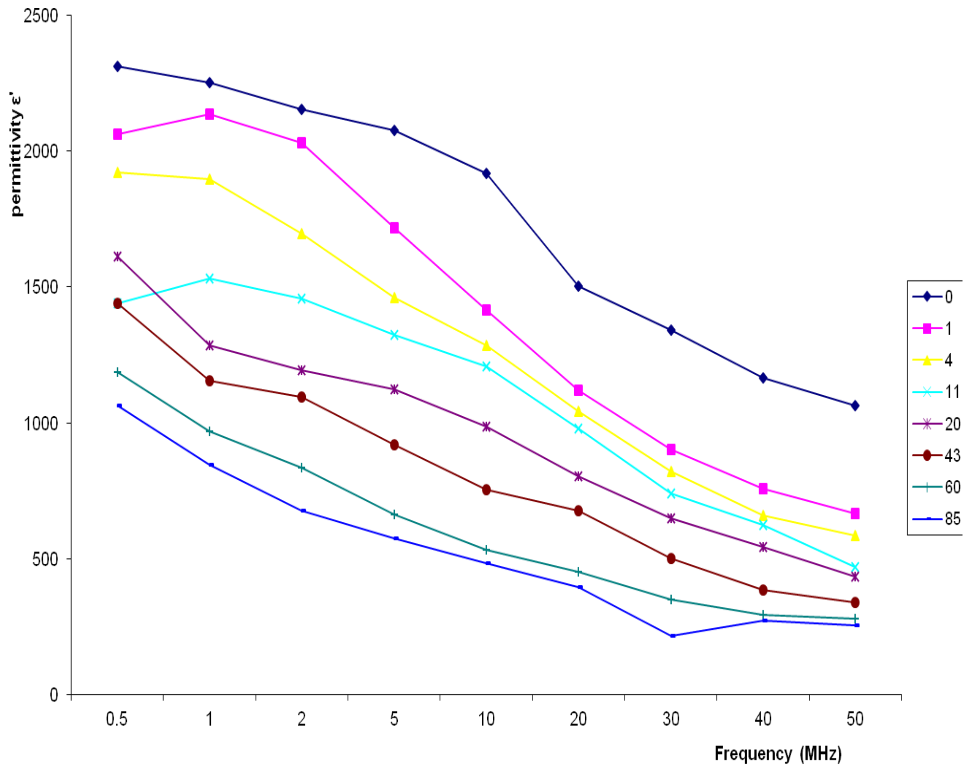

Figure 1. The mean permittivity ε' of ϒ-irradiation and non-irradiated bovin kidney from frequency range of 0.5 to 50.0 mHz.

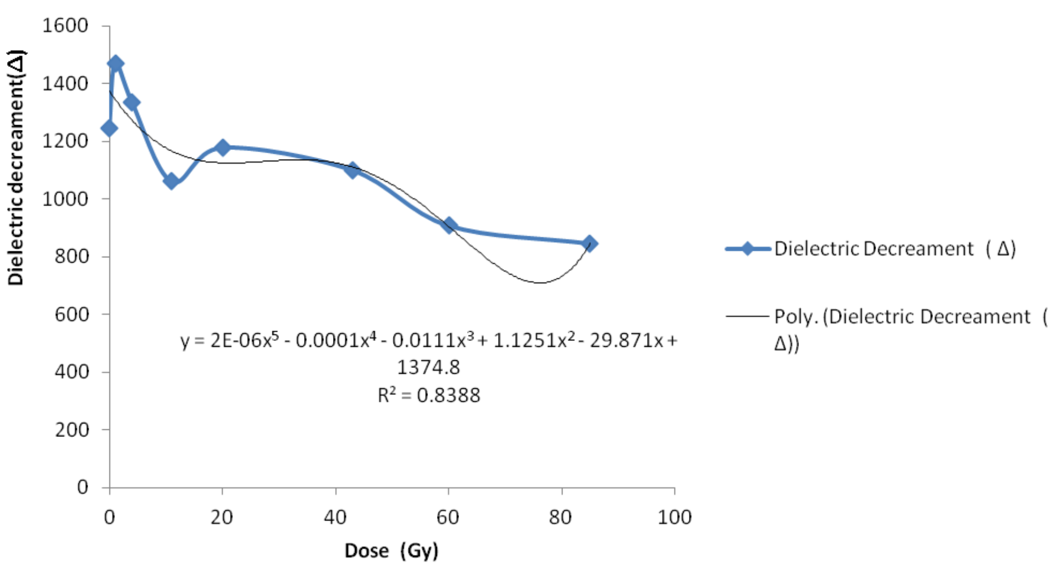

Figure 2. Variation of dielectric decrement with ϒ-irradiation dose for kidney (MHz).

may be as a result of increase in ionization produced by gamma radiation in the irradiated kidney tissues. The spread parameter (α), which isthe degree of heterogeneity in the tissue samples also increased with increase in gamma irradiation doses as shown in Figure 2 and Table 2. The curve of Figure 2 shows a sharp increase in the

Table 2. Dielectric parameter obtained from dielectric dispersion and cole-cole plots for gamma irradiation and non-irradiated bovine kidney.

Dose (Gy)	ε_s	ε_∞	$\Delta(\varepsilon_s - \varepsilon_\infty)$	τ (μs)	α
0	2311.8 ± 120	1054.6 ± 030	1247.2 ± 120	0.318 ± 0.003	0.100 ± 0.002
1	2136.9 ± 117	667.4 ± 018	1469.5 ± 117	0.318 ± 0.003	0.106 ± 0.002
4	1923.0 ± 106	586.8 ± 086	1336.2 ± 106	0.300 ± 0.001	0.104 ± 0.002
11	1531.3 ± 110	470.2 ± 066	1061.1 ± 110	0.294 ± 0.001	0.114 ± 0.004
20	1612.0 ± 124	434.1 ± 036	1177.9 ± 124	0.289 ± 0.003	0.193 ± 0.002
43	1439.6 ± 094	339.5 ± 028	1100.1 ± 094	0.276 ± 0.001	0.305 ± 0.003
60	1186.8 ± 080	278.5 ± 054	908.3 ± 080	0.274 ± 0.002	0.352 ± 0.001
85	1063.3 ± 086	217.2± 076	846.1 ± 086	0.269 ± 0.001	0.341 ± 0.005

spread parameter values from 11Gy to a peak value at 60Gy after which a gradual decrease in the spread parameter began to manifest. This indicates that the ionization produced by gamma irradiation increases the heterogeneous distribution of ions in the kidney tissues (Laogun et al., 2005).

The dieletric permittivity ε' values of $\gamma-$irradiated kidney tissues were found to decrease as the $\gamma-$irradiation doses increase as seen in Table 3 and Figure 3. Consequently, reduction in the dieletric decrement was observed as seen in Figure 4. The curve in figure 4 showed fluctuactions in dielectric permittivity value at 0Gy and a steady decrease at 20Gy – 85Gy. The decrease may be attributed to changes in the integrity and structural properties of the cellular membrane along with the reduction in the Maxwell-Wager interfacial polarization effect, which is responsible for the dielectric permittivity values at the radiofrequencies (Pettig, 1991 and Grant et al., 1978).

The dielectric relaxation time (τ), of the $\gamma-$irradiated kidney tissues decrease as the gamma irradiation doses increased as shown in Figure 5. The curve of figure 5 reveals that the relaxation time decrease steadily between 0Gy and maintained a constant value at 20Gy-43Gy after which a sharp decrease was observed between 43Gy – 85Gy. This suggest that more ions are produce in the irradiated kidney tissue. Thus, time required to charge up the cell membrane of the irradiated kidney tissue decreased.

The mathematical models developed from the dielectric parameter data obtained from experimental investigations (have about 90% fit coefficients.) are presented as:

For spread parameter, α,

(i) Bovine kidney at MHz frequency range (99.4%)

$$y = 3E - 08x^4 - 6E - 06x^3 + 0.101$$

For dielectric decrement, Δ

(ii) Bovine kidney at MHz frequency range (83.8%)

$$y = 2E - 06x^5 - 0.011x^3 + 1.125x^2 - 29.87x + 1374$$

For relaxation time

(iii) Bovine kidney at MHz frequency range (98.2%)

$$y = 2E - 08x^4 - 3E - 06x^3 - 0.004x + 0.318$$

Conclusion

The result of this investigation revealed that, $\gamma-$irradiation doses usually encountered in radiology has measurable effect on the $\gamma-$irradiated mammalian tissue and that, the extent of damage increase with increase in $\gamma-$irradiation doses. Parameters modelled suggests that, these mathematical models are adequate for generation of dielectric data which can be used in the development of dielctric imaging system for diagnosis of certain kidney disesase.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Table 3. The mean permittivity, ε' of ϒ-irradiated and non-irradiated bovine kidney from frequency range 0.5 to 50.0 MHz.

Frequency (MHZ) / Dose (Gy)	Permittivity, ε'								
	0.5	**1.0**	**2.0**	**5.0**	**10**	**20**	**30**	**40**	**50**
0	2311.8 ± 19.6	2250.7 ± 29.6	2153.5 ± 77.8	2075.7 ± 98.2	1917.4 ±139.5	1503.5 ±105.4	1342.4 ± 74.6	1164.6 ± 54.6	1064.6 ± 96.2
1	2061.9 ± 34.2	2136.9 ± 44.6	2031.3 ± 22.6	1717.4 ± 99.2	1414.6 ± 67.8	1120.2 ± 34.7	903.5 ± 48.6	759.1 ± 27.6	667.4 ± 74.8
4	1923.0 ± 98.3	1897.8 ± 79.8	1695.2 ± 77.8	1461.8 ± 58.2	1286.9 ± 60.1	1042.4 ± 38.6	820.2 ± 64.3	659.1 ± 82.8	586.8 ± 62.6
11	1439.6 ± 98.6	1531.3 ± 78.1	1459.1 ± 49.2	1325.7 ± 90.2	1206.5 ± 54.1	978.5 ± 41.8	739.6 ± 37.3	623.0 ± 38.2	470.2 ± 63.2
20	1612.0 ± 29.3	1286.9 ± 44.9	1192.5 ± 74.1	1123.0 ± 81.2	986.8 ± 45.8	803.5 ± 85.1	648.0 ± 42.9	545.2 ± 34.6	434.1 ± 28.6
43	1439.6 ± 34.2	1156.3 ±53.0	1095.4 ± 74.8	920.2 ± 68.1	753.5 ± 68.8	678.5 ± 28.8	500.7 ± 34.8	386.8 ± 37.6	339.5 ± 77.4
60	1186.8 ± 74.3	967.4 ± 48.2	836.8 ± 51.0	661.8 ± 77.8	533.5 ± 70.1	453.5 ± 54.4	350.7 ± 59.2	292.4 ± 76.8	278.5 ± 28.9
85	1063.3 ± 124.6	846.6 ± 91.8	675.8 ± 34.6	575.8 ± 34.8	484.2 ± 66.7	396.2 ± 29.8	217.2 ± 29.4	271.6 ± 55.2	254.9 ± 47.0

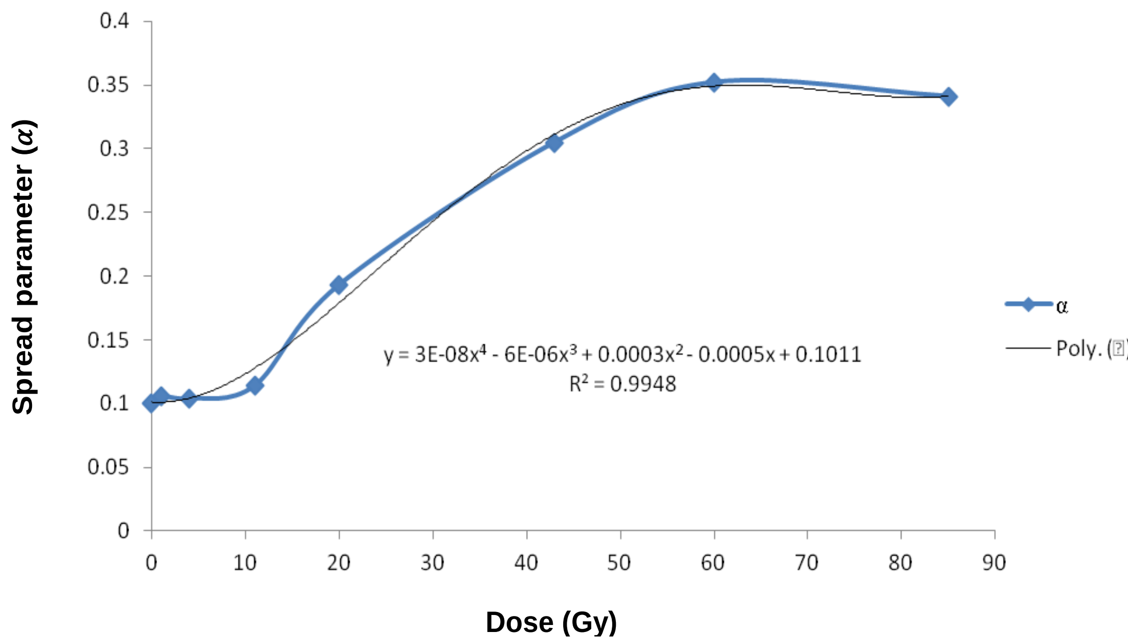

Figure 3. Variation of spread parameter With ϒ-irradiation dose for kidney (MHz).

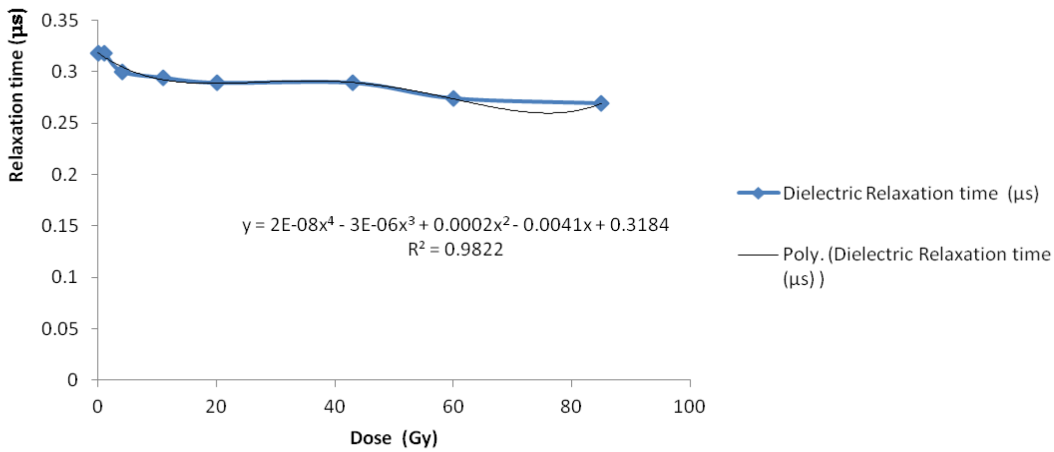

Figure 4. Variation of relaxation time with ϒ-irradiation dose for Kidney (MHz).

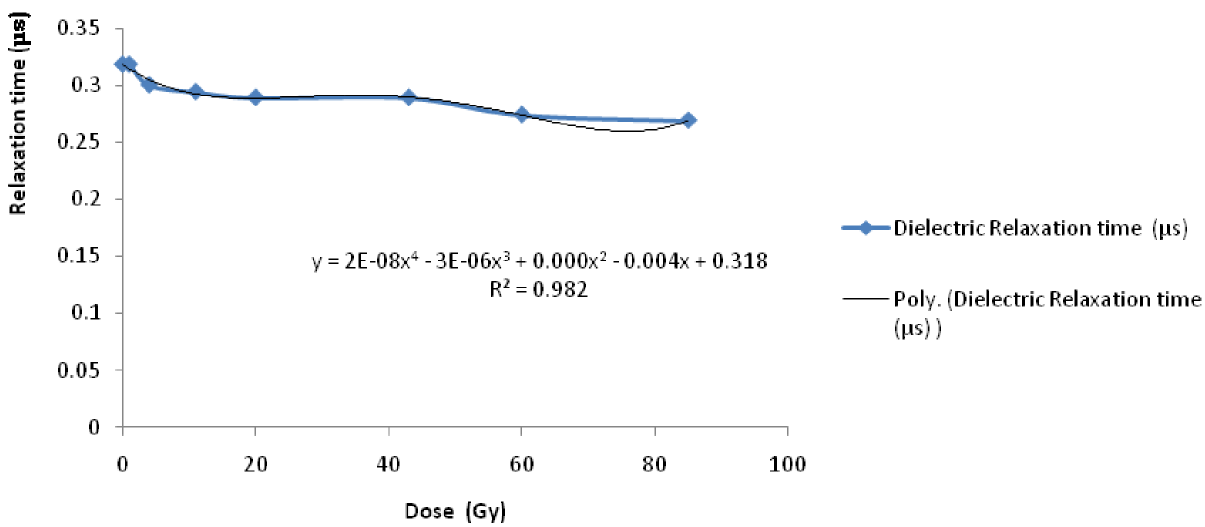

Figure 5. Variation of relaxation time with ϒ-irradiation dose for Kidney (MHz).

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