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Study the Behavior of Some EPR Dosimeters under Different Energies Range

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Abstract: ***An investigation has been done to study the response of various Electron Paramagnetic Resonance (EPR) dosimeters (Alanine, Ammonium tartrate, Lithium oxalate, Sodium carbonate, potassium methionate, Strontium sulfate, Barium dithionate) focusing on low and intermediate photon energy. Different gamma sources of energy ranging from 0.021 to 1.25 MeV (^{103}Pd, ^{170}Tm, ^{99}Tc, ^{192}Ir, ^{137}Cs, ^{65}Zn, and ^{60}Co) which are commonly applied in radiation technology applications were used. A significant variation appeared onthe effective atomic numberZ_{eff} value due to the variations in the dominance of photon interaction process at different energy regions. Compton scattering is a dominant mode of photon interaction, the Z_{eff} can be represented by a mean effective atomic number. A comparison between the results obtained from Auto-Z_{eff} software and single value XMuDat programwas discussed.***

Keywords: effective atomic number, Z_{eff}, EPR dosimetry, low energy, photon interaction

1. Introduction

When introducing a new dosimeter in low energy such as medical and biological applications, its response mainly dependent on the beam qualities used, therefore it must be estimated [1]. A desirable dosimeter should present little or no dependence on the applied beam quality. Electron paramagnet resonance (EPR) dosimetry has been successfully used for radiation dose in many fields including medical and industrial applications. Some of these dosimeters are still being introduced. Alanine [2], strontium sulfate [3], ammonium tartrate [4], Lithium oxalate [5], Barium dithionate [6], and Lithium formate monohydrate [7].

Realizing of the interaction of photon with matter is an important issue [8], the principal modes by which photon interact with matter to be attenuated and to deposit energy is by the photoelectric effect (τ), Compton Effect (σ), and pair production (κ). These are all related to the atomic number Z of the material according to the approximation equations 1, 2, and 3. The atomic number of a material is thus a basic quantity required in determining the penetration of photons in the matter [9].

$$\tau = C.\frac{Z^5}{E^3} \quad (1)$$

$$\sigma = d.\frac{Z}{E} \quad (2)$$

$$\kappa = eZ^2(E - 1.022) \quad (3)$$

Therefore in order to select the preferred dosimeter for a given radiation dose, dosimetric characteristics of the materials must be known, in particular, their energy dependence [10]. A systematic study has been made to describe the behavior of selected EPR dosimeters with different host elements focusing on their response at various energies. The energies of 0.021, 0.084, 0.140, 0.380, 0.661, 1.115.5, 1.250 MeV emitted from radioactive sources ^{103}Pd, ^{170}Tm, ^{99}Tc, ^{192}Ir, ^{137}Cs, ^{65}Zn and ^{60}Co respectively, are widely used in radiation technology for various applications. The effective atomic number (Z_{eff}) values for the selected EPR dosimeters have been determined and the companying effects of using heavy or light elements were discussed. In addition, some recommendations regarding the selection of the future EPR dosimeters have been extracted from this study. This study will be helpful for a future selection of EPR dosimeter particularly when it introduces for medical or biological applications.

2. Theory

2.1 Effective atomic number

A knowledge of $Z_{eff}$is essential to evaluate the energy dependence [11]. Some programs have been used to determine the Z_{eff}, the most suitable method is Auto-Z_{eff} software, and single value XMuDat computer program. Values obtained from the selected method compared also to other referencesbefore submitted [12].

2.1.1 Auto-*Z* eff Method.

Auto-*Z*eff method is quick and easy to use for obtaining the average atomic numbers and spectral-weighted mean atomic numbers. In this method, effective atomic number is determined via exploitation of the smooth correlation between atomic cross-section and atomic number [13]. The effective atomic numbers below 10 keV were not compared due to high uncertainty ±25% by Auto-Z_{eff} software.

2.1.2 XMuDat Method

XMuDat computer program is able to produce a single value of effective atomic number for compounds [14]. The program was furnished by [15], [16]. The program used an imperial relation, assuming that the photoelectric absorption is the main interaction process.

2.2 Energy dependence

The energy dependence was performed by considering the material composition (weight factor) without binder (e.g. paraffin, polyethylene, polyvinyl acetate) table 1. The calculations have been done as its the ratio between the mass energy absorption coefficient (MEAC) of the dosimeter and soft tissue, in the energy range 10 keV to 5 MeV focusing on

the energies emitted of the selected radioisotopes. The work is supported by the standard reference data program of NIST [15] which is more accurate than the other data found in winXcom program.

$$\frac{(\mu_{en}/\rho)_{\text{dosimeter}}}{(\mu_{en}/\rho)_{\text{soft tissue}}} \quad (4)$$

Since (μ_{en}/ρ) is referred to a compound of different elements, we used the additivity rule to calculate it at every energy value;

$$(\mu_{en}/\rho)_{\text{dosimeter}} = (\mu_{en}/\rho)_1 \times w_1 + (\mu_{en}/\rho)_2 \times w_2 + (\mu_{en}/\rho)_3 \times w_3 + n \quad (5)$$

Were (μ_{en}/ρ) is the mass energy absorption coefficient of the element, and w is its fraction by weight.

3. Result and Discussion

The variation of obtained Z_{eff} with energies from selected applied radioactive isotopes illustrated in table 2. An advantage of the auto Z_{eff} program is that it can calculate the effective atomic number according to the interaction dominating, and then it gives the weighted effective atomic number value. On the other hand, XMuDat program has a single value of $Z_{eff,}$ as presented in the table. The value determined by XMuDat is higher than that one determined by auto Z_{eff}, and that because the XMuDat calculates (Z_{eff}) by assuming photoelectric absorption is the main interaction process [17]. The general description of the spectrum behaviors of $Z_{eff,}$ with energy for the selected materials, has several discontinuous jumps, starting constantly at a very small energy range then decreasing steadily as energy increases then become almost constant from (1 to 3 MeV), - this range increases at both sides with the decrease of the host element atomic number - which is due to the fact that at the energy region wherein the Compton scattering is the dominant mode of photon interaction, the Z_{eff} can be represented by a mean atomic number [18]. After that the spectrum undergoes slightly increasing once again then later becomes constant. (See Figure.1.). At low energy, the photoelectric effect is dependent on the highest Z_{eff} (equation 1) this explains why the highest value of the effective atomic number of the dosimeter was produce at this region. That was observed clearly for potassium methionate, strontium sulfate, and barium dithionate where the large atomic number of constituent elements involved. The pair production is a threshold reaction that is impossible below 1.02 MeV and generally doesn't become significant until about 5 MeV, dominated by the increase of the Z_{eff} and the energy (equation 3), appears earlier for the material with high Z_{eff}. Among the considered dosimetric materials, barium dithionate has the highest spread of constituent element while Alanine dosimeter has the least.

Figure.2. shows mass energy-absorption coefficients as a function of photon energy forvariousdosimetric materials in soft tissue,a large discrepancy in the ratio of absorption coefficients may occur at a low energy range by increasing the effective atomic number. Another note may rise when the host element atomic number greater than 20 a large variation in response eliminated particularly at low energies below 0.3 MeV, where small energy dependence found for the light element below 0.1 MeV. However, it was found that the density (see table 3) and the effective atomic number of composite materials were controlled the process of dosimeters response at a low energy range. A preferred dosimeter, which has a density close to the tissue equivalent (~1.042).

4. Conclusions

The present investigation focusing on 7 EPR dosimetric materials evaluated under 0.021-1.25 MeV photon energy, can be concluded in; it's essential to obtain the tissue-equivalent energy dependence use of light element ($1 < Z < 20$) for a host material, determine the effective atomic number and density to avoid the high inner shell ionization. However, even with low Z_{eff} the dosimeter response needs a correction factor in the low energy region in order to obtain optimum results. It's better also to use some binders, which they made a reflection on materials density. A large Z_{eff} generally corresponds to inorganic compounds and metals, whereas a small Z_{eff} (≤ 10) is an indicator of organic substances. For photon interactions, Z_{eff} is not a constant for a composite material but it changes with photon energy due to the interaction processes dominated. In the low energy region, where the photoelectric effect is more dominant there was an agreement between the two methods used to compute the Z_{eff}.

Table 1: Different EPR dosimeters composition with their relative weights in the whole compound.

Name	Formula	Relative weights in the whole compound										∑
		H	O	S	C	N	Li	Na	K	Sr	Ba	
Alanine	$C_3H_7NO_2$	0.08	0.36	-	0.40	0.16	-	-	-	-	-	1
Ammonium tartrate	$(NH_4)_2C_4H_4O_6$	0.07	0.52	-	0.26	0.15	-	-	-	-	-	1
Lithium oxalate	$Li_2C_2O_4$	-	0.63	-	0.24	-	0.13	-	-	-	-	1
Sodium carbonate	Na_2CO_3	-	0.45	-	0.11	-	-	0.44	-	-	-	1
potassium methionate	$K_2CH_2(SO_3)_2$	0.01	0.38	0.25	0.05	-	-	-	0.31	-	-	1
Strontium sulfate	$SrSO_4$	-	0.35	0.17	-	-	-	-	-	0.48	-	1
Barium dithionate	$BaS_2O_6.2H_2O$	0.01	0.39	0.19	-	-	-	-	-	-	0.41	1

Table 2: Effective atomic numbers are calculated with the Auto-Z_{eff} software and single value XMuDat computer program.

Source	Energy (MeV)	Alanine	Ammonium tartrate	Lithium oxalate	Sodium carbonate	Potassium methionate	Strontium sulfate	Barium dithionate
^{103}Pd	0.021	5.5	5.9	7.0	9.2	13.4	23.5	18.4
^{170}Tm	0.084	3.8	4.2	6.4	8.8	11.9	24.8	27.2
^{99}Tc	0.140	3.7	4.1	6.3	8.7	10.3	20.9	26.1
^{192}Ir	0.380	3.7	4.1	6.3	8.7	9.8	15.4	23.6

^{137}Cs	0.661	3.7	4.1	6.3	8.7	9.7	14.8	11.43
^{65}Zn	1.115	3.7	4.1	6.3	8.7	9.7	14.6	10.82
^{60}Co	1.250	3.7	4.1	6.3	8.7	9.7	14.5	10.73
XMuDat (Single value)		6.78	7.13	7.32	9.45	15.22	30.30	41.89

Table 3: Physical densities of most likely EPR dosimeters.

Compound	Density g/cm^3
Alanine	1.42
Ammonium tartrate	1.77
Lithium oxalate	2.12
Sodium carbonate	2.54
potassium methionate	3.03
Strontium sulfate	3.96
Barium dithionate	4.54

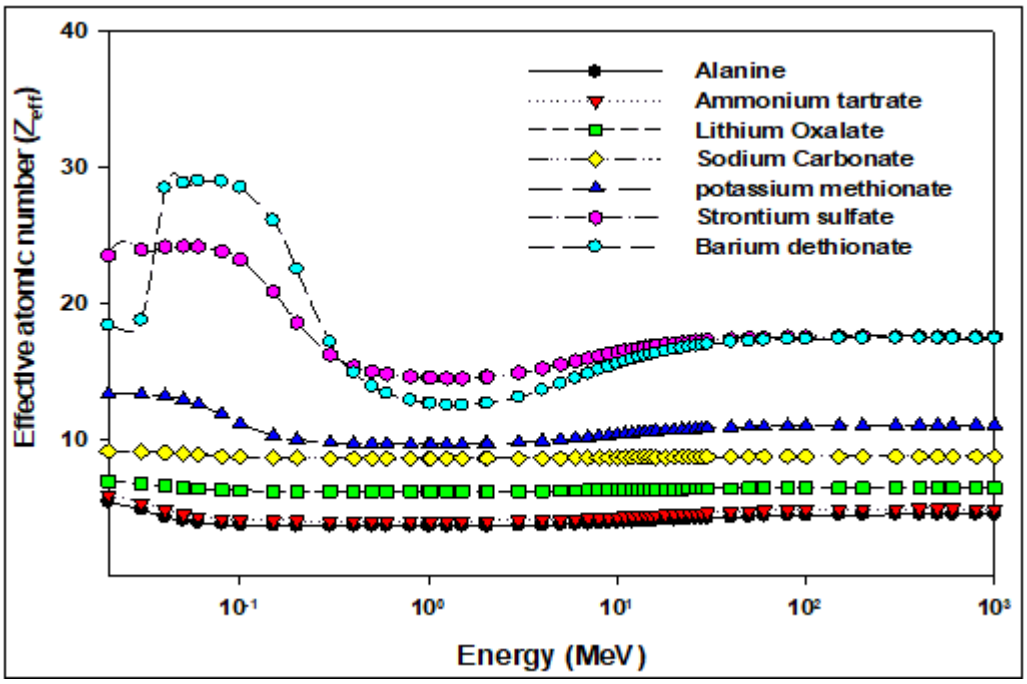

Figure 1: The variations of Z_{eff}, with photon energies for selected EPR dosimeters (Alanine, Ammonium tartrate, Lithium oxalate, Sodium carbonate, potassium methionate, Strontium sulfate, Barium dithionate)

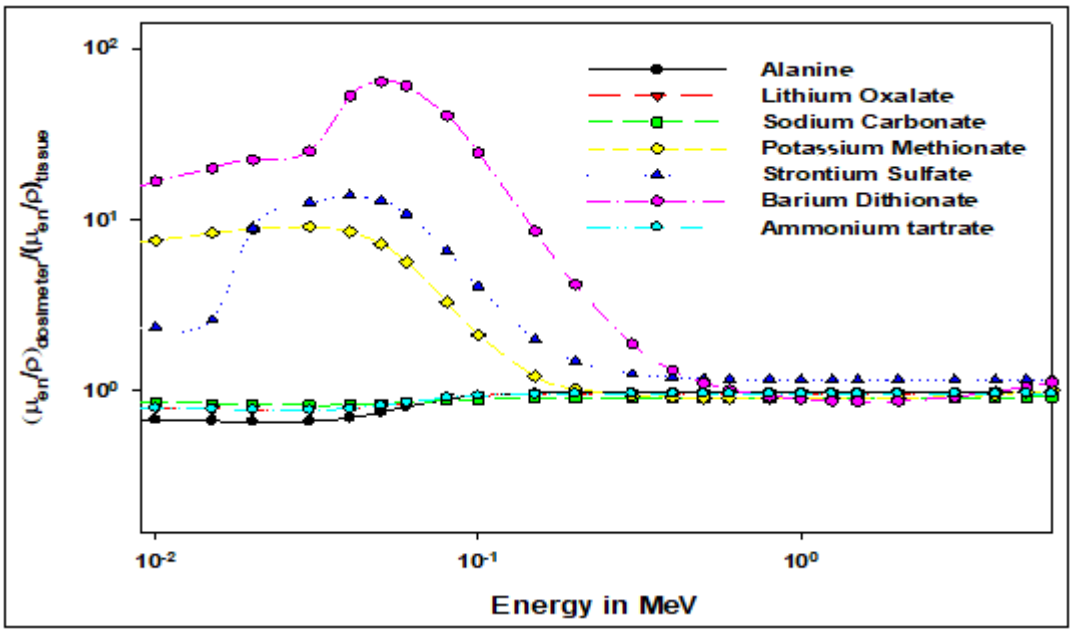

Figure 2: The mass energy absorption coefficient, μ_{en}/ρ, for selected EPR dosimeters (without binders) normalized to soft tissue versus photon energy in the range of 0.01-5 MeV.

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