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Gamma dosimetric parameters in some skeletal muscle relaxants

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Abstract. We have studied the attenuation of gamma radiation of energy ranging from 84 keV to 1330 keV (^{170}Tm, ^{22}Na, ^{137}Cs, and ^{60}Co) in some commonly used skeletal muscle relaxants such as tubocurarine chloride, gallamine triethiodide, pancuronium bromide, suxamethonium bromide and mephenesin. The mass attenuation coefficient is measured from the attenuation experiment. In the present work, we have also proposed the direct relation between mass attenuation coefficient (μ/ρ) and mass energy absorption coefficient (μ_{en}/ρ) based on the nonlinear fitting procedure. The gamma dosimetric parameters such as mass energy absorption coefficient (μ_{en}/ρ), effective atomic number (Z_{eff}), effective electron density (N_{el}), specific γ-ray constant, air kerma strength and dose rate are evaluated from the measured mass attentuation coefficient. These measured gamma dosimetric parameters are compared with the theoretical values. The measured values agree with the theoretical values. The studied gamma dosimetric values for the relaxants are useful in medical physics and radiation medicine.

Keywords. Effective atomic number; electron density; CT number; relaxants.

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1. Introduction

In radiotherapy, γ-rays are capable of interacting with tissues for treatment of malignant neoplasias. These gamma radiations move through the tissues, ionize the medium and cause chemical and biological effects, such as damage to DNA, impairing the replication of neoplastic cells [1] etc. However, the ionizing treatment is not selective, and also affects healthy cells, which makes it toxic for the organism [2]. Although gamma radiation therapy is often an effective method for killing cancer cells, it can also damage nearby blood vessels that nourish the skin, ligaments, tendons, muscles, nerves, bones and lungs. This can result in a progressive condition called radiation fibrosis syndrome (RFS). It generally is an after-effect of radiotherapy. Medications are needed to control pain and muscle spasms in RFS. Muscle relaxants are used to treat this disorder which may help relieve the pain associated with muscle spasms [3].

After the γ-ray therapy for cancer, the complications are more predictable, often more severe, and can lead to permanent tissue changes that put the patient at risk for serious chronic complications. Skeletal muscle relaxants are advised to relieve the pain [4]. After the first round of radiotherapy treatment, muscle relaxants are injected to relieve the pain. During the second or subsequent cycles, some muscle relaxants still remain in the tissues. To determine the dose to cancerous cell during the second or subsequent doses, we should consider the attenuation of γ-rays in cancerous cells and attenuation in skeletal muscle relaxants in the tissues. The measurement of mass attenuation coefficient in cancerous tissues alone will not give correct attenuation factor for cancerous tissue after the first dose. Hence measurement of mass attenuation coefficient in skeletal muscle relaxants helps in the correction of attenuation in cancerous tissues after the first dose. This corrected attenuation in cancerous tissues (which is injected by skeletal muscle relaxants after the first dose) helps in determining the doses to skeletal muscle relaxants. Literature suvery shows that there are some studies on measurements of mass attenuation coefficient of cancerous cells [5–7]. But literature survey also reveals that there is no such studies on measurements in the skeletal muscle relaxants. Hence there is a need to measure the mass attenuation coefficient in skeletal muscle relaxants.

To know the after-effects of radiation on skeletal muscle, it is important to consider the attenuation in

skeletal muscle relaxants also. As radiotherapy can cause adverse effects later, the severity of these effects is directly related to the quality of radiation and the dose-fractionation protocol. Hence it is important to study the gamma dosimetric parameters in skeletal muscle relaxants. Head and neck radiotherapy causes countless sequelae in irradiated patients, affecting the stomatognathic system, with significant systemic implications. After the head and neck radiotherapy, skeletal muscle relaxants are advised to relieve the pain and that may improve the quality of life for oncologic patients [2]. Photons in the keV range are important in radiation biology as well as in medical diagnostics and therapy [8]. Photons in the MeV range are important in the field of radiography and medical imaging, and photons in the GeV range are important in astrophysics and cosmology. Hine [9] stated that a single number cannot represent Z_{eff} of a complex material. The parameter Z_{eff} is very useful in choosing a substitute composite material in place of an element for that energy depending on the requirement. Several investigators have measured or calculated Z_{eff} for human tissue and other biological materials [10–12]. So far, to our knowledge, no study has been done for skeletal muscle relaxants (biomedical compounds).

In the present work, we have measured the mass attenuation coefficients of some commonly used skeletal muscle relaxants such as tubocurarine chloride, gallamine triethiodide, pancuronium bromide, suxamethonium bromide and mephenesin for various gamma sources of energy ranging from 84 keV to 1330 keV (^{170}Tm, ^{22}Na, ^{137}Cs and ^{60}Co). In the present work, we have also proposed the direct relation between mass attenuation coefficient (μ/ρ) and mass energy absorption coefficient (μ_{en}/ρ) based on the nonlinear fitting procedure. The gamma dosimetric parameters such as mass energy absorption coefficient (μ_{en}/ρ), effective atomic number (Z_{eff}), effective electron density (N_{el}), specific γ-ray constant, air kerma strength and dose rate are evaluated from the measured mass attentuation coefficient. These measured gamma dosimetric parameters are compared with the theoretical values.

2. Present work

2.1 *Theory*

2.1.1 *Calculation of effective atomic number.* The effective atomic number is calculated using the following equation:

$$Z_{\text{eff}} = \frac{\sigma_{\text{atm}}}{\sigma_{\text{ele}}} = \frac{(\mu/\rho)_{\text{bio}} \left(\sum_i n_i A_i / \sum_i n_i\right)}{\sum_i \left(f_i A_i / Z_i\right) (\mu/\rho)_i}. \tag{1}$$

Here, n_i is the number of atoms of the ith element and A_i is its atomic weight in a given molecule. f_i is the fractional abundance, $(\mu/\rho)_i$ is the mass attenuation coefficient of the ith element. The mass attenuation coefficient of relaxants using $(\mu/\rho)_{\text{bio}}$ is obtained by running WinXCOM program (2004). In the present work, we have generated mass attenuation coefficients using WinXCom [13]. This program uses the same underlying cross-sectional database as the well-known tabulation of Hubbell and Seltzer [14]. The composition of the skeletal muscle relaxants is given in table 1.

2.2 *Computation of electron density* (N_{e})

The effective electron density, N_{e}, expressed as the number of electrons per unit mass is closely related to the effective atomic number. For a chemical element, the electron density is given by $N_{\text{el}} = NZ/A$. This expression can be generalized to a compound as

$$N_{\text{e}} = \frac{N}{\sum_i n_i A_i} Z_{\text{eff}} \sum_i n_i. \tag{2}$$

In the present work, we have calculated N_{el} using the above equation.

2.2.1 *Relation between mass attenuation coefficient and mass energy absorption coefficient.* There is no direct relationship between mass attenuation coefficient and dose, since not every attenuated photon deposits all its energy in the medium. There is a related quantity called the mass energy absorption coefficient that can be multiplied by the photon fluence to calculate the

Table 1. Composition of skeletal muscle relaxants.

Skeletal muscle relaxants	H	C	N	O	Cl	Br	I
Gallamine triethiodide	0.067834	0.404167	0.047132	0.053838	–	–	0.427030
Mephenesin	0.077441	0.659151	–	0.263409	–	–	–
Pancuronium bromide	0.082541	0.573763	0.038234	0.087347	–	0.218114	–
Suxamethonium chloride	0.086249	0.423200	0.070503	0.241598	0.178451	–	–
Tubocurarine chloride	0.067916	0.575857	0.036299	0.228050	0.091878	–	–

dosimetric quantity. Literature shows that there is no direct relationship between mass attenuation coefficient and mass energy absorption coefficient. In the previous work, it is assumed that the mass energy absorption and the mass attenuation coefficients are almost the same. So, in such case, one can approximately presume that the dose absorbed in the material is proportional to its mass attenuation coefficient. This is not correct as there is a difference in the values of mass energy absorption and the mass attenuation coefficient. In the present work, we have proposed the following direct relation between mass attenuation coefficient and mass energy absorption coefficient based on the nonlinear fitting procedure:

$$\frac{\mu_{\text{en}}}{\rho} = \left(6.07468102 \times 10^{-3} Z + 0.6010954763 + \frac{2.767586461}{Z} - \frac{2.854094714}{Z^2}\right) \times \left(\frac{\mu}{\rho}\right)^{(1.006874529(e^{(-1.219206944 \cdot Z)}+1))}. \quad (3)$$

The above emperical relation is valid for the elements H, C, N, O, Cl, Br and I. For the compounds containing these elements, atomic number $Z = Z_{\text{eff}}$ and the above relation becomes

$$\frac{\mu_{\text{en}}}{\rho} = \left(6.07468102 \times 10^{-3} Z_{\text{eff}} + 0.6010954763 + \frac{2.767586461}{Z_{\text{eff}}} - \frac{2.854094714}{Z_{\text{eff}}^2}\right) \times \left(\frac{\mu}{\rho}\right)^{(1.006874529(e^{(-1.219206944 \cdot Z_{\text{eff}})}+1))}. \quad (4)$$

We have provided the relation between mass attenuation coefficient and mass energy absorption coefficient, so that relationship between mass attenuation coefficient and dose can be achieved.

2.2.2 *Specific γ-ray constant.* Specific γ-ray constant (Γ) is the exposure rate (in R/h) due to photons at a distance of 1 m from a source with an activity of 1 Ci

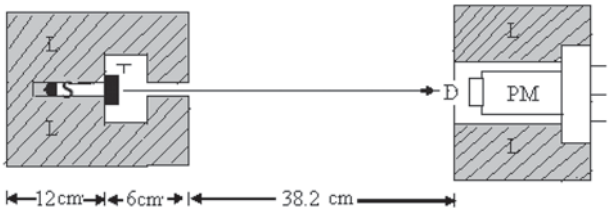

Figure 1. Schematic diagram of the experimental set-up. S – source position, T – target sample, L – lead shielding, D – detector, PM – photomultiplier.

Specific γ-ray constant for given gamma energy is calculated by substituting μ_{en}/ρ from eq. (4).

2.2.3 *Dose and dose rate.* Dose (D) and dose rate (D_{rate}) at a distance r and time t from a source of activity A are represented by the following equations:

$$D = \frac{\Gamma C t}{r^2} \quad (6)$$

$$D_{\text{rate}} = \frac{\Gamma C}{r^2} \quad (7)$$

$$D_{\text{rate}} = \dot{\psi}\left(\frac{\mu_{\text{en}}}{\rho}\right) = \frac{CE}{4\pi r^2}\left(\frac{\mu_{\text{en}}}{\rho}\right). \quad (8)$$

Here $\dot{\psi}$ is the energy fluence rate (MeV/cm^{2}s), C is the activity in Bq, E is the energy per decay (MeV) and (μ_{en}/ρ) is the mass energy absorption coefficient.

2.2.4 *Air kerma strength.* The source activity as a function of photons emitted per second can be expressed as

$$N_{\text{photon}} = A \times 2.363. \quad (9)$$

The air kerma strength (S_{k}) measures the strength of radiotherapeutic source, which was first introduced by AAPM task group report number 32 [15,16]. For convenience, it is denoted by U where 1 U = 1 μGy m^2 h^{-1} = 1 cGy cm^2 h^{-1}. Air kerma strength is defined as the product of air kerma rate in free space at a distance d, $K_{\text{air}}(d)$ and square of the distance, r:

$$S_{\text{k}} = \dot{K_{\text{air}}} \times r^2. \quad (10)$$

$$\Gamma = \frac{E_\gamma(\text{MeV/decay}) \times (1.6 \times 10^{-13}\ \text{J/MeV}) \times ((\mu_{\text{en}}/\rho)\ \text{cm}^2/\text{g}) \times (3600\ \text{s/h}) \times (3.7 \times 10^{10}\ \text{Bq/Ci})}{4\pi(34(\text{J/kg})/(\text{C/kg})) \times (100\ \text{cm/m})^2 \times (2.58 \times 10^{-4}\ (\text{C/kg})/\text{R}) \times (10^{-3}\ \text{kg/g}) \times (\text{Bq}/(\text{decay/s}))}$$

$$\Gamma = 657.68 \times E_\gamma \left(\frac{\mu_{\text{en}}}{\rho}\right) \frac{\text{Rm}^2}{\text{Ci h}}. \quad (5)$$

Table 2. Comparison of measured [5] mass attenuation coefficients (cm^2/g) with theoretical values.

	Gallamine triethiodide		Mephenesin		Pancuronium bromide		Suxamethonium chloride		Tubocurarine chloride	
Source	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.
^{170}Tm (84 keV)	1.467	1.569	0.172	0.184	0.376	0.403	0.191	0.205	0.18	0.192
^{22}Na (511 keV)	0.096	0.102	0.093	0.098	0.093	0.098	0.093	0.099	0.092	0.097
^{137}Cs (662 keV)	0.083	0.088	0.083	0.088	0.083	0.087	0.084	0.089	0.082	0.087
^{60}Co (1170 keV)	0.063	0.067	0.066	0.07	0.065	0.069	0.067	0.07	0.066	0.07
^{22}Na (1274 keV)	0.058	0.061	0.061	0.064	0.06	0.063	0.061	0.064	0.06	0.064
^{60}Co (1330 keV)	0.057	0.06	0.06	0.064	0.059	0.062	0.06	0.064	0.059	0.063

Table 3. Comparison of measured Z_{eff} with theoretical values.

	Gallamine triethiodide		Mephenesin		Pancuronium bromide		Suxamethonium chloride		Tubocurarine chloride	
Source	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory
^{170}Tm (84 keV)	24.22	23.251	3.67	3.472	7.38	7.203	4.35	4.206	4.01	3.958
^{22}Na (511 keV)	3.67	3.523	3.59	3.396	3.96	3.865	3.83	3.704	3.65	3.603
^{137}Cs (662 keV)	4.8	4.608	3.64	3.443	3.88	3.787	3.71	3.588	3.96	3.909
^{60}Co (1170 keV)	4.62	4.435	3.64	3.443	3.77	3.68	3.71	3.588	3.97	3.918
^{22}Na (1274 keV)	4.62	4.435	3.64	3.443	3.78	3.689	3.71	3.588	3.97	3.918
^{60}Co (1330 keV)	4.62	4.435	3.64	3.443	3.77	3.68	3.71	3.588	3.96	3.909

Table 4. Comparison of measured N_{el} with theoritical values.

	Gallamine triethiodide	Mephenesin	Pancuronium bromide	Suxamethonium chloride	Tubocurarine chloride
84 keV					
Expt.	1.61	0.32	0.62	0.36	0.34
Theory	1.546	0.303	0.605	0.348	0.336
511 keV					
Expt.	0.327	0.325	0.323	0.326	0.321
Theory	0.314	0.307	0.315	0.315	0.317
662 keV					
Expt.	0.327	0.325	0.321	0.326	0.321
Theory	0.314	0.307	0.313	0.315	0.317
1170 keV					
Expt.	0.327	0.325	0.32	0.326	0.321
Theory	0.314	0.307	0.312	0.315	0.317
1274 keV					
Expt.	0.327	0.325	0.32	0.326	0.321
Theory	0.314	0.307	0.312	0.315	0.317
1330 MeV					
Expt.	0.326	0.324	0.319	0.325	0.32
Theory	0.313	0.307	0.311	0.314	0.316

The air kerma strength per unit source activity (S_k/A) (in UBq) is calculated from mass energy absorption coefficients by using the following equation:

$$\frac{S_k}{A} = 3.6 \times 10^9 \times 1.602 \times 10^{-10} \times 2.363 \times \sum_{0}^{E_{\max}} \Phi(E_i) \times \frac{\mu_{\text{en}}(E_i)}{\rho} \Delta E, \quad (11)$$

where E_i is the energy of the ith particle, $\mu_{\text{en}}(E_i)/\rho$ is the mass energy absorption coefficient and $\Phi(E_i)$ (MeV cm^{-2}) is the photon fluence differential and it is given by

$$\Phi(E_i) = \frac{E_i}{4\pi r^2}. \quad (12)$$

The factor 1.602×10^{-10} is required to convert K_{air} from MeV g^{-1} to Gy. The factor 2.363 is taken from the

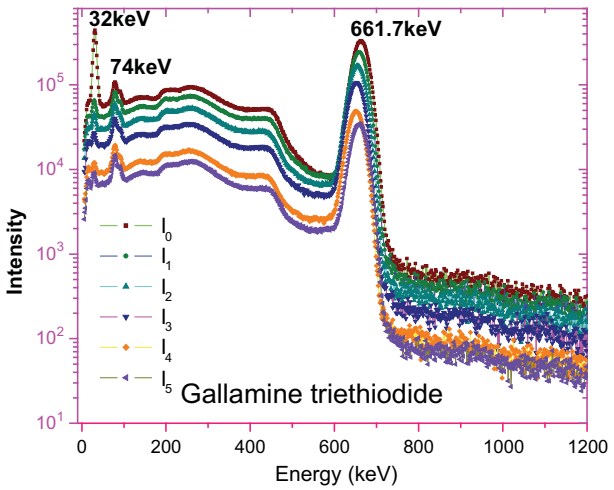

Figure 2. The measured ^{137}Cs spectrum for different thicknesses of gallamine triethiodide sample.

relation between source activity and photons emitted per second. The factor 3.6×10^9 is used to convert the unit Gy m^2 s^{-1} Bq^{-1} to UB q^{-1}. The air kerma strength per unit source activity equation becomes

$$\frac{S_k}{A} = 1.36279 \times \sum_{0}^{E_{max}} \frac{E_i}{4\pi r^2} \times \frac{\mu_{en}(E_i)}{\rho} \Delta E. \qquad (13)$$

Air kerma strength per unit source activity (cGy h^{-1} U^{-1}) for given gamma energy is calculated by substituting μ_{en}/ρ from eq. (4).

3. Experiment

We have measured mass attenuation coefficients using transmission experiment. Transmission experiments with the narrow beam (good-geometry) set-up were used for measuring the incident and transmitted intensities, and hence calculating the attenuation coefficient. The narrow geometry experimental set-up is shown in figure 1. In the present experiment, NaI(Tl)-based gamma spectrometry technique was used. This γ-ray spectrometry system consists of a high efficiency GSpec. The GSpec consists of an NaI(Tl) crystal detector of size 5.8×5.8 cm^2 and multichannel analyser (MCA). GSpec has built-in 14 Pin PMT base. The GSpec is the pc-based γ-ray spectroscopy system, which communicates with PC through the USB port. The voltage divider and pulse processing circuitry are housed as front-end electronics in GSpec. This plug-in PMT on GSpec makes it compatible with any NaI(Tl) detector with standard 14 Pin PMT. GSpec is powered through USB port. NaI(Tl) detector PMT requires around 1000 V DC. These voltages are generated by DC–DC convertors operating on

Table 5. Comparison of measured mass energy absorption coefficient with theoritical values.

Source	Gallamine triethiodide		Mephenesin		Pancuronium bromide		Suxamethonium chloride		Tubocurarine chloride	
	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory
^{170}Tm (84 keV)	1.261E+00	1.347E+00	1.941E−01	2.098E−01	3.617E−01	3.900E−01	2.084E−01	2.256E−01	1.998E−01	2.140E−01
^{22}Na (511 keV)	1.072E−01	1.146E−01	1.041E−01	1.105E−01	1.025E−01	1.086E−01	1.031E−01	1.104E−01	1.027E−01	1.086E−01
^{137}Cs (662 keV)	8.773E−02	9.395E−02	9.253E−02	9.886E−02	9.165E−02	9.652E−02	9.342E−02	9.953E−02	9.021E−02	9.602E−02
^{60}Co (1170 keV)	6.698E−02	7.192E−02	7.326E−02	7.824E−02	7.180E−02	7.655E−02	7.421E−02	7.792E−02	7.235E−02	7.697E−02
^{22}Na (1274 keV)	6.161E−02	6.541E−02	6.761E−02	7.139E−02	6.616E−02	6.976E−02	6.745E−02	7.111E−02	6.568E−02	7.027E−02
^{60}Co (1330 keV)	6.054E−02	6.432E−02	6.648E−02	7.139E−02	6.507E−02	6.865E−02	6.633E−02	7.111E−02	6.459E−02	6.918E−02

Table 6. Comparison of measured specific γ-ray constant ($Rm^2/Ci\,h$) with theoretical values.

Source	Gallamine triethiodide		Mephenesin		Pancuronium bromide		Suxamethonium chloride		Tubocurarine chloride	
	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory
^{170}Tm (84 keV)	6.97E+01	7.44E+01	1.07E+01	1.16E+01	2.00E+01	2.16E+01	1.15E+01	1.25E+01	1.10E+01	1.18E+01
^{22}Na (511 keV)	3.60E+01	3.85E+01	3.50E+01	3.71E+01	3.45E+01	3.65E+01	3.47E+01	3.71E+01	3.45E+01	3.65E+01
^{137}Cs (662 keV)	3.82E+01	4.09E+01	4.03E+01	4.30E+01	3.99E+01	4.20E+01	4.07E+01	4.33E+01	3.93E+01	4.18E+01
^{60}Co (1170 keV)	5.15E+01	5.53E+01	5.64E+01	6.02E+01	5.53E+01	5.89E+01	5.71E+01	6.00E+01	5.57E+01	5.92E+01
^{22}Na (1274 keV)	5.16E+01	5.48E+01	5.67E+01	5.98E+01	5.54E+01	5.85E+01	5.65E+01	5.96E+01	5.50E+01	5.89E+01
^{60}Co (1330 keV)	5.30E+01	5.63E+01	5.82E+01	6.25E+01	5.69E+01	6.01E+01	5.80E+01	6.22E+01	5.65E+01	6.05E+01

5 V DC supply from the USB port. Power supply for the instrument is +5 V for digital circuits and +9 and −9 V for analog circuits. High voltage supply is generated by programmable HV module. It can generate HV up to 1200 V DC. Calibration of multichannel analyser converts the channel number to incident gamma energy. In the present work, calibration was done using ^{60}Co (1.17 MeV, 1.333 MeV) and ^{137}Cs (0.662 MeV).

Gamma sources such as ^{170}Tm (0.084 MeV), ^{22}Na (0.511 MeV), ^{137}Cs (0.662 MeV), ^{60}Co (1.170 MeV), ^{22}Na (1.274 MeV) and ^{60}Co (1.330 MeV) are used. The sample was directly attached to the opening of the lead shield where the source is placed. The emitted γ-rays from the sources were allowed to bombard the sample and attenuated γ-rays were measured by NaI(Tl) detector. In the case of ^{60}Co which emits two γ-rays with 1.17 and 1.33 MeV energy, the gamma spectrum of ^{60}Co measured by NaI(Tl) detector gives two separate peaks of different counts corresponding to 1.17 and 1.33 MeV energy. ^{22}Na also emits two γ-rays with 0.511 and 1.274 MeV energy. The gamma spectrum of ^{22}Na measured by NaI(Tl) detector gives separate peaks of different counts corresponding to 0.511 and 1.274 MeV energy. These counts are proportional to their attenuation properties which depend on the gamma energy. Thus, separate energies are selected from their attenuated gamma spectrum measured by NaI detector. The integral intensities I_0 and I of the beam before and after passing through the sample, are measured for sufficient time. I_0 is the intensity corresponding to zero thickness of the sample. I is the intensity corresponding to the thickness t of the sample. (μ/ρ) is then estimated using the relation

$$\frac{\mu}{\rho} = \left(\frac{1}{t\rho}\right) \ln\left(\frac{I_0}{I}\right), \tag{14}$$

where t and ρ are the thickness and density of the sample, respectively.

4. Results and discussions

The typical measured ^{137}Cs spectrum for different thicknesses of gallamine triethiodide sample is shown in figure 2. In this figure, I_0 is the intensity corresponding to zero thickness of the sample. I_1, I_2, I_3, I_4 and I_5 are intensities of the spectrum corresponding to different thicknesses of the sample in increasing order. The measured (μ/ρ) values are compared with theoretical values and it is given in table 2. The measured values agree with the theoretical values. The values of these parameters have been found to change with energy and interaction of γ-ray with the medium.

Table 7. Comparison of measured air kerma strength (cGy h^{-1} U^{-1}) with theoretical values.

Source	Gallamine triethiodide		Mephenesin		Pancuronium bromide		Suxamethonium chloride		Tubocurarine chloride	
	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory	Expt.	Theory
^{170}Tm (84 keV)	5.34E−02	5.70E−02	8.21E−03	8.87E−03	1.53E−02	1.65E−02	8.82E−03	9.54E−03	8.45E−03	9.05E−03
^{22}Na (511 keV)	1.02	1.09	9.91E−01	1.05	9.76E−01	1.03	9.82E−01	1.05	9.78E−01	1.03
^{137}Cs (662 keV)	1.82	1.94	1.92	2.05	1.90	2.00	1.93	2.06	1.87	1.99
^{60}Co (1170 keV)	7.66	8.22	8.37	8.94	8.21	8.75	8.48	8.91	8.27	8.80
^{22}Na (1274 keV)	9.09	9.65	9.98	10.50	9.76	10.30	9.95	10.50	9.69	10.40
^{60}Co (1330 keV)	10.20	10.80	11.20	12.00	10.90	11.50	11.10	11.90	10.80	11.60

Table 8. Estimated dose rate (dD/dt) [5].

Skeletal muscle relaxants	Source	Energy (MeV)	Dose rate (Gy/S)
Gallamine triethiodide	^{21}Na	0.511	4.51E+06
	^{137}Cs	0.6616	6.47E+03
	^{52}Mn	0.835	3.02E+01
	^{60}Co	1.173	9.63E+03
	^{22}Na	1.274	1.01E+03
	^{60}Co	1.332	1.05E+04
Mephenesin	^{21}Na	0.511	3.99E+06
	^{137}Cs	0.6616	6.17E+03
	^{52}Mn	0.835	3.04E+01
	^{60}Co	1.173	1.00E+04
	^{22}Na	1.274	1.06E+03
	^{60}Co	1.332	1.11E+04
Pancuronium bromide	^{21}Na	0.511	4.01E+06
	^{137}Cs	0.6616	6.12E+03
	^{52}Mn	0.835	3.00E+01
	^{60}Co	1.173	9.88E+03
	^{22}Na	1.274	1.04E+03
	^{60}Co	1.332	1.09E+04
Suxamethonium chloride	^{21}Na	0.511	4.00E+06
	^{137}Cs	0.6616	6.17E+03
	^{52}Mn	0.835	3.04E+01
	^{60}Co	1.173	1.01E+04
	^{22}Na	1.274	1.07E+03
	^{60}Co	1.332	1.11E+04
Tubocurarine chloride	^{21}Na	0.511	3.94E+06
	^{137}Cs	0.6616	6.08E+03
	^{52}Mn	0.835	3.00E+01
	^{60}Co	1.173	9.95E+03
	^{22}Na	1.274	1.05E+03
	^{60}Co	1.332	1.10E+04

Comparisons of the measured Z_{eff} and N_{el} with theoretical values for a given gamma source are shown in tables 3 and 4. In the present work, we have also proposed the direct relation between mass attenuation coefficient (μ/ρ) and mass energy absorption coefficient (μ_{en}/ρ) based on the nonlinear fitting procedure. This relation may be used for compounds or mixture containing elements such as H, C, N, O, Cl, Br and I. The measured mass energy absorption coefficient (μ_{en}/ρ) is compared with the theoritical values and is shown in table 5. Table 6 shows comparison of measured specific γ-ray constant ($\text{Rm}^2/\text{Ci h}$) with theoretical values. The specific γ-ray constant values are different for different gamma sources. The comparisons of measured air kerma strength (cGy h^{-1} U^{-1}) with theoretical values are shown in table 7. This air kerma strength per unit activity increases by increasing the energy of the source. The evaluated absorbed dose rates from the measured

mass attenuation coefficients at a distance 1 m from point gamma sources like ^{21}Na, ^{137}Cs, ^{52}Mn, ^{60}Co and ^{22}Na in skeletal muscle relaxants are shown in table 8. Absorbed dose rate in the relaxants is maximum for ^{21}Na and minimum for ^{52}Mn. The measured values agree with the theoretical values. The studied gamma dosimetric values for the relaxants are useful in medical physics and radiation medicine.

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