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Bazı Radyodiagnostik Ajanların Radyasyon Koruyucu Parametrelerinin Teorik İncelenmesi

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ÖZ

Tıbbi görüntülemenin sağlık hizmetlerindeki etkisi her geçen gün artmaktadır. Bu sayede hastalıklar daha erken teşhis edilebilir ve tedaviler daha etkin bir şekilde yürütülebilir. Tıbbi görüntülemenin kullanımı teşhisin ötesine geçerek hastalık önleme ve tedavi alanlarına ulaştığından, küresel ölçekte sağlık hizmetlerinin maliyetleri de önemli ölçüde azalmaktadır. Bu çalışmada, görüntülemede kullanılan $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic asit), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetik asit) ve $C_{20}H_{12}O_5$ (Fluorescein) gibi ilaçların radyasyon koruyucu özellikleri araştırılmıştır. Bu radyasyon parametreleri, lineer ve kütle zayıflama katsayılarını (LAC, MAC), yarım ve onuncu değer katmanlarını (HVL, TVL), ortalama serbest yolu (MFP), etkin atom numarası ve elektron yoğunluğunu (Z_{eff}, N_{eff}) ve etkin iletkenlik enerjisini (C_{eff}) içerir ve bunlar Phy-X yazılımı kullanılarak hesaplanmıştır. Bu veriler 1 keV ile 2 MeV enerji bölgesi aralığı için üretilmiştir. Elde edilen verilere göre bu enerji değerinden sonra 100 keV'a kadar saçılan verilerin birbiriyle uyumlu olduğu görülmüştür.

Theoretical Investigation of Some Radiation Shielding Parameters of Radiodiagnostic Agents

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ABSTRACT

The impact of medical imaging in health services is increasing day by day. In this way, diseases can be diagnosed earlier and treatments can be carried out more effectively. As the use of medical imaging goes beyond diagnosis and reaches the areas of disease prevention and treatment, the costs of healthcare services on a global scale are also significantly reduced. In this study, radiation shielding properties of drugs such as $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) and $C_{20}H_{12}O_5$ (Fluorescein) used in imaging have been investigated. These radiation parameters include linear and mass attenuation coefficients (LAC, MAC), half and tenth value layers (HVL, TVL), mean free path (MFP), effective atomic number and electron density (Z_{eff}, N_{eff}) and effective conductivity (C_{eff}) energy by using Phy-X software. These data have been generated for 1 keV to 2 MeV energy region. According to the data obtained, it was seen that the data scattered up to 100 keV were compatible with each other after this energy value.

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1. Introduction

The impact of medical imaging in health services is increasing day by day. In this way, diseases have the opportunity to be diagnosed earlier, so that treatments can be carried out more effectively. With the expansion of usage areas, Medical imaging goes beyond diagnosis and reaches the areas of disease prevention and treatment. Thus, the costs of health services on a global scale are also significantly reduced. With the use of X-ray devices in medicine, the developments in the past 20-30 years have brought medical science to another era. In particular, the latest point reached in imaging systems, besides signing important developments in the medical world by doctors, serves human health to a great extent (Krane and Lynch, 1989).

Radiodiagnostic means radiological imaging, and information of existing diseases is obtained by this method by extracting medical images of a certain part or all of the human body. These images can be obtained by x-rays or changes in magnetic fields. Radiodiagnostic images, obtained by means of radiodiagnostic devices and providing easier diagnosis, not only provided easy diagnosis, but also helped diseases to become treatable with more specific methods (Kavun et al., 2019). so that the diseases are now diagnosed when they are in their infancy or at the beginning stage, and thus the patients; have the opportunity to be treated by being less affected by the side effects of the treatment (Martin and Tanır, 2013).

Radiation, which is the emission or transfer of energy in the form of electromagnetic waves or particles, can be emitted from natural and artificial sources. Most of the radiation received by unnatural means is of medical origin. Medical radiation is of particular importance for patients exposed to X-ray used for diagnosis or to radiotherapy and nuclear medicine applications used for diagnosis and treatment (Kavun et al., 2019b). The doses received here are larger than those from other man-made sources. For these reasons, radiation shielding materials are being developed to protect against radiation and its destructive effects (Martin and Tanır, 2013; Kavun et al., 2021).

$C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid) improves the quality of the collected information of lesion characterization and liver lesions. It is a contrast agent developed to obtain images with high sensitivity and accuracy provided by contrast-enhanced computed tomography (CT) and magnetic resonance imaging (MRI) (Bormann et al., 2015). Because of its magnetic effect, MRI examination is more sensitive to gadolinium effect than CT is more commonly used iodine. The first of the 3 reasons for this is that thin contrasted areas that cannot be selected in CT can be selected in MRI examination. Second, the dose of iodine used in CT is considerably higher than the dose of gadolinium used in MRI. Third, late-phase vascular structures can be monitored more clearly than parenchyma (Kadıyoran, 2010).

$C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid), a gadolinium-based MR contrast agent, is used for Imaging blood vessels and inflamed or diseased tissue where blood vessels are leaking. It is often used when imaging intracranial lesions with abnormal vascularity or abnormalities in the blood–brain barrier. It is injected intravenously (Murphy et al., 1996).

$C_{20}H_{12}O_5$ (Fluorescein) is a fluorophore widely used in the microscope, dye laser, forensics, and serology to detect occult blood spots and in dye tracking. It appears yellow-green in normal tear film and bright green in a more alkaline environment such as aqueous humor (Gessner, 2000). It is a phthalic indicator dye used therapeutically as an aid in the diagnosis of corneal injuries and corneal trauma (Duvall and Kershner, 2006).

Radio frequency (RF) shielding of an MR scanner is mandatory (Seunghoon et al., 2010). With this shielding, foreign electromagnetic radiation can be prevented from contaminating/distorting the MR signal, and is to prevent electromagnetic radiation generated by the MR scanner from causing interference to nearby medical devices (Weibler, 1993). In addition to all these, the basis of radiation protection is to reduce the exposure dose to which individuals are exposed. For this reason, the radiation shielding properties of the material used in radiation protection should be known and the radiation absorption properties of this material and its effectiveness in protecting living tissue should be known(Knoll and Kraner, 1981; Krane and Lynch, 1989).

In this study, radiation shielding properties of drugs such as $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) and $C_{20}H_{12}O_5$ (Fluorescein) used in imaging have been investigated. These radiation parameters include linear and mass attenuation coefficients (LAC, MAC), half and tenth value layers (HVL, TVL), mean free path (MFP), effective atomic number and electron density (Z_{eff}, N_{eff}) and effective conductivity (C_{eff}) energy by using Phy-X software (Şakar et al., 2020). These data have been generated for 1 keV to 2 MeV energy region. According to the data obtained, it was seen that the data scattered up to 100 keV were compatible with each other after this energy value.

2. Materials and Methods

Online Photon Shielding and Dosimetry (PSD) software has been developed for calculating parameters related to shielding and dosimetry. Phy-X / PSD online software (Şakar et al., 2020) is running on remote server and operating system is Ubuntu. The linear and mass attenuation coefficients (LAC, MAC), half and tenth value layers (HVL, TVL), mean free path (MFP), effective atomic number and electron density (Z_{eff}, N_{eff}), effective conductivity (C_{eff}) energy absorption parameters can be calculated by using Phy-X software (Şakar et al., 2020). It can generate data in the continuous energy region of 1 keV-100 GeV (Şakar et al., 2020). In order to calculate the radiation protection parameters of any material, users must register with the Phy-X platform with their academic e-mail addresses. There are three steps required for calculation in the software: Definition of materials, Selection of energies and Selection of parameters to be calculated (Şakar et al., 2020).

In the Eq.(1), The linear absorption coefficient (LAC) can be calculated with the Beer–Lambert law (Agar, 2018):

$$\mu = \ln\left(\frac{I_0}{I}\right) / (-x) \qquad (\mathrm{cm}^{-1}) \qquad (1)$$

Here, x is material thickness and I is the number of photon reaching the detector by interacting with the thin film, and I_0 is the number of photon reaching the detector without interacting with the material.

The Mass Attenuation Coefficient (MAC) (μ_m) is given in Eq. (2) for a compound and mixture (Eskalen et al., 2020):

$$\mu_m = \frac{\mu}{\rho} = \sum w_i \left(\frac{\mu}{\rho}\right)_i \quad (\mathrm{cm^2/g})$$

(2)

here, w_i is the weight fraction and ρ is density and the mass attenuation coefficient is given by $\left(\frac{\mu}{\rho}\right)_i$ for elements in the compound (Sim et al., 2021) (Eskalen et al., 2020).

The required thicknesses to reduce the radiation intensities by one half and one tenth are HVL and TVL , respectively (Şakar et al., 2020);

$$HVL = \frac{\ln 2}{\mu} \qquad (\mathrm{cm})$$

(3)

$$TVL = \frac{\ln 10}{\mu} \qquad (\mathrm{cm})$$

(4)

The Mean Free Path (MFP) is average distance of photon moves without interacting with the material (Şakar et al., 2020);

$$MFP = \frac{1}{\mu} \qquad (\mathrm{cm})$$

(5)

Equation (8) and (9) represents the effective atomic number (Z_{eff}) and effective electron density (N_{eff}). They can be used in the interaction of dosimeters with radiation and in the calculation of radiation interactions with tissues (Un and Caner, 2014; Şakar et al., 2020).

$Z_{eff} = \frac{\sigma_a}{\sigma_{e^-}}$

(8) $N_{eff} = \frac{(\mu/\rho)_m}{\sigma_{e^-}}$ (6.02x10^{23} e$^-$/g)

(9)

σ_a is effective atomic cross section and it is given in eq. 10:

$$\sigma_a = \frac{1}{N_A}\sum f_i A_i \left(\frac{\mu}{\rho}\right)_i$$

(10)

f_i is the fractional abundance of the element and effective electronic cross section is given in eq.11 as follows:

$$\sigma_e = \frac{1}{N_A}\sum \frac{f_i A_i}{Z_i}\left(\frac{\mu}{\rho}\right)_i$$

(11)

Z_i is the atomic number of ith element (Un and Caner, 2014):

Effective conductivity of materials is directly proportional to the C_{eff} and given by following equation (Şakar et al., 2020):

$$C_{eff} = \left(\frac{N_{eff}\,\rho e^2\tau}{m_e}\right)10^3$$

(12)

Here, e (C) is charge mass of electron and and m_e (kg) is mass of electron. τ (s) is relaxation time of the electron at the Fermi Surface (Şakar et al., 2020).

3. Results and Discussion

In this study, in order to know the radiation absorption amount of $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) and $C_{20}H_{12}O_5$ (Fluorescein) drugs in the body, some radiation shielding parameters have been investigated. According to this theoretical investigation that is made by using Phy-X software we made between 1 keV and 2 MeV energies, the LAC values varies between 3061.419 and 0.05 cm^{-1} for $C_{23}H_{30}GdN_3O_{11}$. Depending on LAC values, the MAC value varies between 2813.546 and 0.046 cm^2/g. Similar to this, HVL values varies between 0.0002 and 13.879 cm. TVL and MFP values are 0.008 and 0.0003 cm at 1 keV and 46.105 and 20.023 cm at 2 MeV energy respectively. Z_{eff} values have been fluctuated between 8.40 and 5.17 and N_{eff} have similar behavior between 5.04*10^{23} and 3.11*10^{23} electrons/g. Lastly, C_{eff} values have been obtained between 3.96*10^8 and 2.44*10^8 s/m. These values can be seen in Table 1. Also, Figure 1 illustrates of these values detailly.

Table 1. Radiation shielding parameters of $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid) by using Phy-X software

Energy (MeV)	MAC (cm^2/g)	LAC (1/cm)	HVL (cm)	TVL (cm)	MFP (cm)	Z_{eff}	N_{eff} (electrons/g)	C_{eff} (S/m)
1.00E-03	2813.546	3061.419	0.000	0.001	0.000	8.40	5.04E+23	3.96E+08
1.50E-03	1913.316	2081.879	0.000	0.001	0.000	15.30	9.19E+23	7.22E+08
2.00E-03	1106.423	1203.899	0.001	0.002	0.001	18.68	1.12E+24	8.82E+08
3.00E-03	399.634	434.842	0.002	0.005	0.002	20.96	1.26E+24	9.89E+08
4.00E-03	190.352	207.122	0.003	0.011	0.005	22.61	1.36E+24	1.07E+09
5.00E-03	106.334	115.702	0.006	0.020	0.009	23.90	1.44E+24	1.13E+09
6.00E-03	65.890	71.695	0.010	0.032	0.014	24.95	1.50E+24	1.18E+09
8.00E-03	99.188	107.927	0.006	0.021	0.009	44.39	2.67E+24	2.09E+09
1.00E-02	64.867	70.582	0.010	0.033	0.014	47.21	2.84E+24	2.23E+09
1.50E-02	22.426	24.402	0.028	0.094	0.041	46.94	2.82E+24	2.21E+09
2.00E-02	10.517	11.443	0.061	0.201	0.087	44.42	2.67E+24	2.10E+09
3.00E-02	3.659	3.981	0.174	0.578	0.251	36.04	2.17E+24	1.70E+09
4.00E-02	1.776	1.933	0.359	1.191	0.517	27.47	1.65E+24	1.30E+09
5.00E-02	1.048	1.141	0.608	2.019	0.877	20.94	1.26E+24	9.88E+08
6.00E-02	2.857	3.108	0.223	0.741	0.322	37.39	2.25E+24	1.76E+09
8.00E-02	1.418	1.543	0.449	1.492	0.648	27.52	1.65E+24	1.30E+09
1.00E-01	0.841	0.915	0.757	2.516	1.093	20.59	1.24E+24	9.72E+08
1.50E-01	0.364	0.396	1.752	5.821	2.528	11.96	7.18E+23	5.64E+08
2.00E-01	0.228	0.248	2.796	9.290	4.034	8.71	5.23E+23	4.11E+08
3.00E-01	0.142	0.155	4.474	14.864	6.455	6.52	3.92E+23	3.08E+08
4.00E-01	0.113	0.123	5.654	18.782	8.157	5.83	3.50E+23	2.75E+08
5.00E-01	0.097	0.106	6.556	21.778	9.458	5.54	3.33E+23	2.61E+08
6.00E-01	0.087	0.095	7.309	24.279	10.544	5.39	3.23E+23	2.54E+08
8.00E-01	0.074	0.081	8.575	28.486	12.371	5.24	3.15E+23	2.47E+08
1.00E+00	0.066	0.072	9.671	32.128	13.953	5.17	3.11E+23	2.44E+08
1.50E+00	0.053	0.058	11.998	39.856	17.309	5.13	3.08E+23	2.42E+08
2.00E+00	0.046	0.050	13.879	46.105	20.023	5.17	3.11E+23	2.44E+08

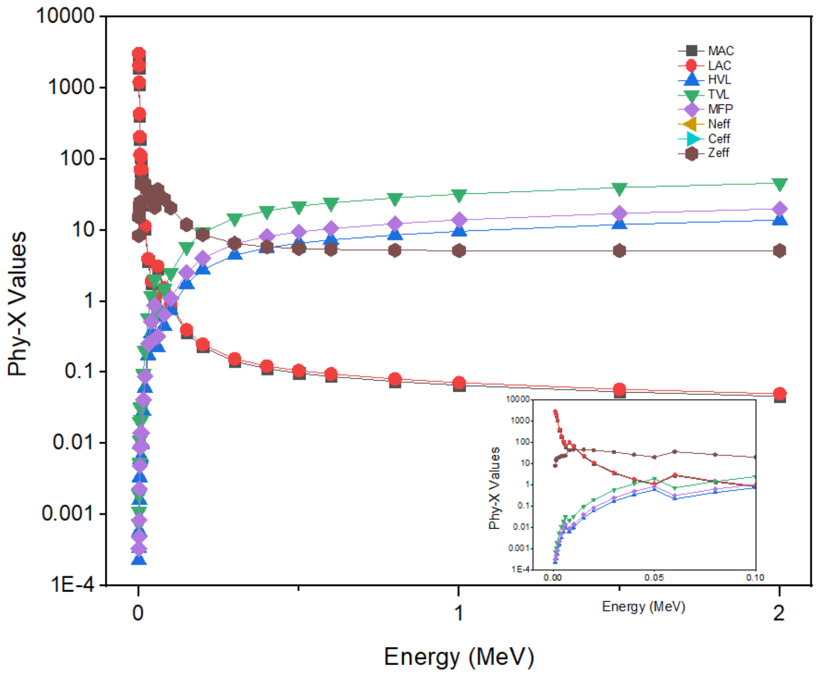

Figure 1. The obtanied Phy-X software data of $C_{23}H_{30}GdN_3O_{11}$

The radiation shielding values for $C_{28}H_{54}GdN_5O_{20}$ can be seen in Figure 2. The LAC values varies between 8671.355 and 0.135 cm^{-1} for $C_{28}H_{54}GdN_5O_{20}$. The MAC value varies between 2990.122 and 0.047 cm^2/g. Similar to this, HVL values varies between 0.00008 and 5.125 cm. TVL and MFP values are 0.00027 and 0.00012 cm at 1 keV and 17.024 and 7.393 cm at 2 MeV energy respectively. Z_{eff} values have been fluctuated between 8.09 and 4.56 and N_{eff} have similar behavior between $5.61*10^{23}$ and $3.16*10^{23}$ electrons/g. Lastly, C_{eff} values have been obtained between $1.17*10^9$ and $6.62*10^8$ s/m. These values can be seen in Table 2.

Table 2. Radiation shielding parameters of $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) by using Phy-X software

Energy (MeV)	MAC (cm^2/g)	LAC (1/cm)	HVL (cm)	TVL (cm)	MFP (cm)	Z_{eff}	N_{eff} (electrons/g)	C_{eff} (S/m)
1.00E-03	2990.122	8671.355	0.000	0.000	0.000	8.09	5.61E+23	1.17E+09
1.50E-03	1705.602	4946.245	0.000	0.000	0.000	12.85	8.91E+23	1.86E+09
2.00E-03	944.494	2739.032	0.000	0.001	0.000	15.32	1.06E+24	2.22E+09
3.00E-03	333.927	968.388	0.001	0.002	0.001	17.02	1.18E+24	2.47E+09
4.00E-03	156.921	455.072	0.002	0.005	0.002	18.28	1.27E+24	2.65E+09
5.00E-03	86.812	251.755	0.003	0.009	0.004	19.28	1.34E+24	2.80E+09
6.00E-03	53.392	154.837	0.004	0.015	0.006	20.11	1.39E+24	2.92E+09
8.00E-03	74.405	215.775	0.003	0.011	0.005	38.38	2.66E+24	5.57E+09
1.00E-02	48.337	140.179	0.005	0.016	0.007	41.50	2.88E+24	6.02E+09
1.50E-02	16.680	48.371	0.014	0.048	0.021	41.07	2.85E+24	5.96E+09
2.00E-02	7.833	22.715	0.031	0.101	0.044	38.10	2.64E+24	5.53E+09
3.00E-02	2.752	7.981	0.087	0.289	0.125	29.19	2.02E+24	4.24E+09
4.00E-02	1.360	3.944	0.176	0.584	0.254	21.23	1.47E+24	3.08E+09

5.00E-02	0.821	2.381	0.291	0.967	0.420	15.80	1.10E+24	2.29E+09
6.00E-02	2.131	6.179	0.112	0.373	0.162	30.33	2.10E+24	4.40E+09
8.00E-02	1.079	3.130	0.221	0.736	0.319	21.14	1.47E+24	3.07E+09
1.00E-01	0.657	1.905	0.364	1.209	0.525	15.45	1.07E+24	2.24E+09
1.50E-01	0.305	0.883	0.785	2.607	1.132	9.08	6.29E+23	1.32E+09
2.00E-01	0.202	0.587	1.181	3.924	1.704	6.86	4.76E+23	9.97E+08
3.00E-01	0.135	0.393	1.766	5.866	2.547	5.42	3.76E+23	7.87E+08
4.00E-01	0.110	0.320	2.165	7.191	3.123	4.98	3.45E+23	7.23E+08
5.00E-01	0.097	0.280	2.473	8.214	3.567	4.79	3.32E+23	6.95E+08
6.00E-01	0.087	0.254	2.734	9.082	3.944	4.69	3.25E+23	6.81E+08
8.00E-01	0.075	0.218	3.181	10.567	4.589	4.60	3.19E+23	6.67E+08
1.00E+00	0.067	0.194	3.574	11.871	5.156	4.55	3.16E+23	6.61E+08
1.50E+00	0.054	0.157	4.421	14.687	6.379	4.53	3.14E+23	6.57E+08
2.00E+00	0.047	0.135	5.125	17.024	7.393	4.56	3.16E+23	6.62E+08

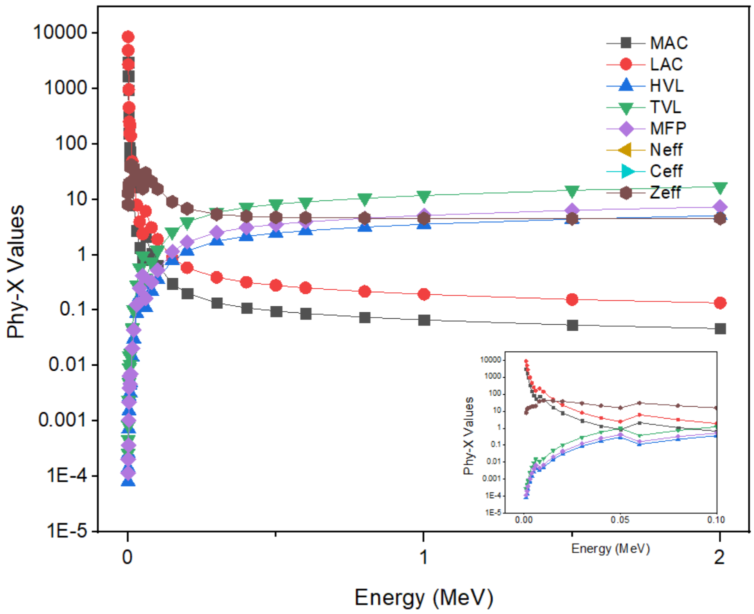

Figure 2. The obtanied Phy-X software data of $C_{28}H_{54}GdN_5O_{20}$

$C_{20}H_{12}O_5$ data can be seen in Figure 3 that is calculated to determine of radiation shielding properties. The LAC values starts from 4330.560 cm^{-1} at 1 keV and it changes up to 0.071 cm^{-1} at 2 MeV energy. In these energy ranges, the MAC value have been varied between 2703,221 and 0,046 cm^2/g. HVL values have been changed between 0.00016 and 9.398 cm. TVL and MFP values are 0.00053 and 0.00023 cm at 1 keV and 31.218 and 13.558 cm at 2 MeV energy, respectively. Z_{eff} values have been changed between 6.68 and 4.66 and N_{eff} have similar behavior between $4.48*10^{23}$ and $3.12*10^{23}$ electrons/g. Lastly, C_{eff} values have been obtained between $5.18*10^8$ and $3.61*10^8$ s/m. All these values can be seen in Table 3.

Table 3. Radiation shielding parameters of $C_{20}H_{12}O_5$ (Fluorescein) by using Phy-X software

Energy (MeV)	MAC (cm^2/g)	LAC (1/cm)	HVL (cm)	TVL (cm)	MFP (cm)	Z_{eff}	N_{eff} (electrons/g)	C_{eff} (S/m)
1.00E-03	2703.221	4330.560	0.000	0.001	0.000	6.68	4.48E+23	5.18E+08
1.50E-03	879.230	1408.526	0.000	0.002	0.001	6.71	4.50E+23	5.20E+08
2.00E-03	386.053	618.457	0.001	0.004	0.002	6.73	4.51E+23	5.22E+08
3.00E-03	117.569	188.345	0.004	0.012	0.005	6.74	4.52E+23	5.23E+08
4.00E-03	49.752	79.703	0.009	0.029	0.013	6.75	4.53E+23	5.23E+08
5.00E-03	25.366	40.636	0.017	0.057	0.025	6.75	4.52E+23	5.23E+08
6.00E-03	14.595	23.381	0.030	0.098	0.043	6.74	4.52E+23	5.22E+08
8.00E-03	6.122	9.807	0.071	0.235	0.102	6.69	4.48E+23	5.19E+08
1.00E-02	3.162	5.066	0.137	0.454	0.197	6.60	4.43E+23	5.12E+08
1.50E-02	1.039	1.665	0.416	1.383	0.601	6.25	4.19E+23	4.85E+08
2.00E-02	0.541	0.867	0.799	2.656	1.153	5.84	3.91E+23	4.53E+08
3.00E-02	0.289	0.463	1.496	4.971	2.159	5.24	3.51E+23	4.06E+08
4.00E-02	0.225	0.360	1.924	6.390	2.775	4.96	3.32E+23	3.84E+08
5.00E-02	0.199	0.318	2.177	7.231	3.140	4.83	3.24E+23	3.74E+08
6.00E-02	0.185	0.296	2.345	7.790	3.383	4.76	3.19E+23	3.69E+08
8.00E-02	0.168	0.269	2.575	8.553	3.715	4.71	3.16E+23	3.65E+08
1.00E-01	0.157	0.252	2.748	9.127	3.964	4.68	3.14E+23	3.63E+08
1.50E-01	0.140	0.224	3.096	10.284	4.466	4.66	3.13E+23	3.62E+08
2.00E-01	0.127	0.204	3.394	11.274	4.896	4.66	3.12E+23	3.61E+08
3.00E-01	0.111	0.177	3.914	13.003	5.647	4.65	3.12E+23	3.61E+08
4.00E-01	0.099	0.158	4.374	14.529	6.310	4.65	3.12E+23	3.61E+08
5.00E-01	0.090	0.145	4.791	15.916	6.912	4.65	3.12E+23	3.61E+08
6.00E-01	0.083	0.134	5.182	17.214	7.476	4.65	3.12E+23	3.61E+08
8.00E-01	0.073	0.117	5.901	19.603	8.513	4.65	3.12E+23	3.61E+08
1.00E+00	0.066	0.106	6.564	21.803	9.469	4.65	3.12E+23	3.61E+08
1.50E+00	0.054	0.086	8.064	26.787	11.633	4.65	3.12E+23	3.61E+08
2.00E+00	0.046	0.074	9.398	31.218	13.558	4.66	3.12E+23	3.61E+08

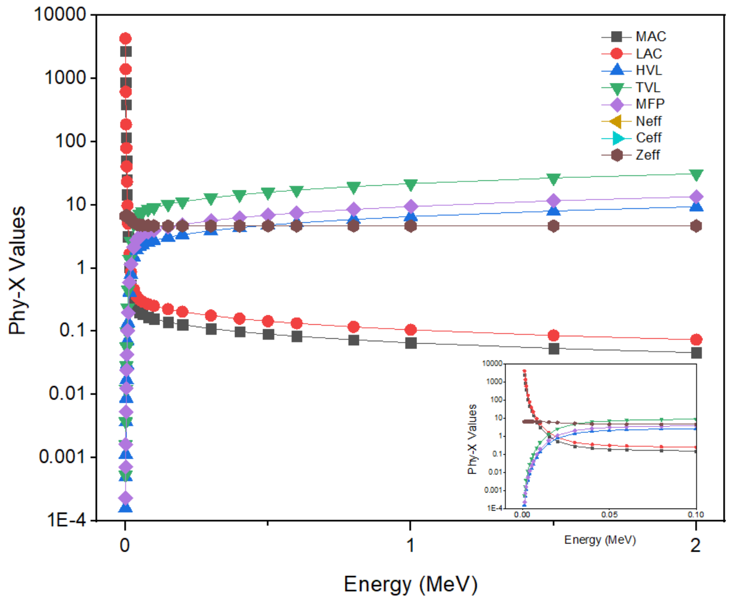

Figure 3. The obtanied Phy-X software data of $C_{20}H_{12}O_5$

4. Conclusions

In this study, radiation shielding properties of $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) and $C_{20}H_{12}O_5$ (Fluorescein) imaging agents were investigated in order to measure the radiation permeability in the body. These radiation shielding parameters are linear and mass attenuation coefficients (LAC, MAC), half and tenth value layers (HVL, TVL), mean free path (MFP), effective atomic number and electron density (Z_{eff}, N_{eff}) and effective conductivity (C_{eff}) energy have been calculated theoretically by using the Phy-X software. These calculations have been performed between 1 keV and 2 MeV energy range. According to the obtained values, The LAC and MAC values decreased continuously up to 2 MeV energy. As can be seen from these results, these compounds interact with radiation particles. On the contrary, it was observed that the values of HVL, TVL and MFP increased as the energy increased. As can be seen from these results, the radiation permeability of these compounds is low. Z_{eff}, N_{eff} and C_{eff} values other than these did not show dependence on energy and different values were obtained at different energies, that is, a fluctuation was observed. According to all these results, it has been observed that $C_{23}H_{30}GdN_3O_{11}$ (Gadoxetic acid), $C_{28}H_{54}GdN_5O_{20}$ (Gadopentetic acid) and $C_{20}H_{12}O_5$ (Fluorescein) imaging agents have high efficiency at low energies. Thus, it was concluded that these compounds can be used efficiently in image acquisition.

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Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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