

STUDY OF EFFECTIVE ATOMIC NUMBERS AND ELECTRON DENSITIES, KERMA OF ALCOHOLS, PHANTOM AND HUMAN ORGANS, AND TISSUES SUBSTITUTES

by

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Effective atomic numbers (Z_{Peff}) and electron densities of eighteen alcohols such as wood alcohol, CH_3OH ; grain alcohol, $\text{C}_2\text{H}_5\text{OH}$; rubbing alcohol, $\text{C}_3\text{H}_7\text{OH}$; butanol, $\text{C}_4\text{H}_9\text{OH}$; amyl alcohol, $\text{C}_5\text{H}_{11}\text{OH}$; cetyl alcohol, $\text{C}_{16}\text{H}_{33}\text{OH}$; ethylene glycol, $\text{C}_2\text{H}_4(\text{OH})_2$; glycerin, $\text{C}_3\text{H}_5(\text{OH})_3$; PVA, $\text{C}_2\text{H}_4\text{O}$; erythritol, $\text{C}_4\text{H}_6(\text{OH})_4$; xylitol, $\text{C}_5\text{H}_7(\text{OH})_5$; sorbitol, $\text{C}_6\text{H}_8(\text{OH})_6$; volemitol, $\text{C}_7\text{H}_9(\text{OH})_7$; allyl alcohol, $\text{C}_3\text{H}_5\text{OH}$; geraniol, $\text{C}_{10}\text{H}_{17}\text{OH}$; propargyl alcohol, $\text{C}_3\text{H}_3\text{OH}$; inositol, $\text{C}_6\text{H}_6(\text{OH})_6$, and menthol, $\text{C}_{10}\text{H}_{19}\text{OH}$ have been calculated in the photon energy region of 1 keV-100 GeV. The estimated values have been compared with experimental values wherever possible. The comparison of Z_{Peff} of the alcohols with water phantom and PMMA phantom indicate that the ethylene glycol, glycerin, and PVA are substitute for PMMA phantom and PVA is substitute of water phantom. Z_{Peff} of alcohols have also been compared with human organs and tissues. Ethylene glycol, glycerin and PVA, allyl alcohol, and wood alcohols are found tissue substitutes for most of human organs. Kerma which is the product of the energy fluence and mass energy-absorption coefficient, have been calculated in the energy region from 1 keV to 20 MeV for the alcohols. The results show the kerma is more or less independent of energy above 100 keV.

Key words: alcohol, phantom, effective atomic number, human tissue, gamma, kerma

INTRODUCTION

Gamma interaction with matter is thrust area in radiation measurement, nuclear physics, radiation physics, medical physics, radiation dosimetry, radiation protection, radiation biology, nuclear technology, clinical applications as well as in medical diagnostics [1] and space research [2]. Gamma radiation is measured by radiation detectors of various mediums such as solid, liquid, and gaseous. The radiation dose absorbed by human body is measured by dosimeters of equivalent atomic number. Dosimeters of such type are selected for dose measurement such as LiF personal dosimeters and radiation monitors. Quality assurance of the dosimeters is carried out by calibration of the dosimeters on human body equivalent phantom. Water and poly-methyl-metha-crylate (PMMA) are the versatile materials suitable for standard phantoms used for radiotherapy and radiation dosimetry due to closest human body tissue equivalent [3]. Other various tissue equivalent materials such as Perspex, plas-

tic, rubber, glass borosilicate, A-5 tissue equivalent materials such as wax, plastic or solid water are available for dosimetric analysis. Some alcohols have been recently used for dosimetric applications [4].

Mass attenuation coefficients (μ/ρ), effective atomic number (Z_{eff}) and effective electron densities (N_{eff}) are the dosimetric interest parameters for the photon interaction. The mass attenuation coefficient is a measure of photon interaction with matter; it is used to derive the molecular, atomic cross-section, effective atomic number and effective electronic density. Any parameter of the above can be used for photon interaction study. The photon interacts with medium by photo-absorption, Compton scattering and pair-production process which depends on the photon energy and constituent atomic number of the elements. The photo-absorption and pair-production are the complete photon removal process whereas Compton interaction slows down photon energy and then is removed by photo-absorption interaction.

The theoretical values for mass attenuation coefficients and cross-sections of about 100 different elements, compounds, and mixtures have been compiled by Berger and Hubbell [5] and given in the form of XCOM software at energies 1 keV to 100 GeV which

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has been transformed to WinXcom software at window platform for easy export in excel form [6, 7]. Mass attenuation coefficients, effective atomic numbers and electron densities of composite materials are photon energy dependent. The mass attenuation coefficients of material at various energies are used for estimation of effective atomic number by ratio effective atomic cross-section to effective electronic cross-section. A similar program XmuDat also calculates mass attenuation coefficient, mass energy transfer, mass attenuation coefficients for elements, compounds, and mixtures in the energy range from 1 to 50 MeV photon energy range for the medical physics interest [8].

Several researchers have studied photon interaction parameters like the Z_{eff} and N_{eff} for various composite materials at photon energy from 1 keV to 1 GeV [9], total mass attenuation coefficients, effective atomic and electron numbers for PbO, barite, colemanite, tincal, and ulexite at 80.1, 302.9, 356.0, 661.7, and 1250.0 keV photon energies [10], effective atomic number of the composite materials such as bakelite, nylon, teflon *etc.* in the photon energy region 280-1115 keV by measuring the incoherent scattering cross-section [11], spin ice compounds and concrete shielding materials [12, 13]. The most useful photon interaction parameter, Z_{eff} and N_{eff} , are available for few solutions [14], thermoluminescent dosimeters [15], organic compounds [16], gases and gaseous mixture [17], amino acids [18], fatty acids and carbohydrates [19], photon interaction parameters of common solvents [20], and mass attenuation coefficients of ethanol have been experimentally investigated in photon energy 0.123-1.33 MeV [21].

In the present work, we have selected dosimetric interest of eighteen alcohols containing H, C, and O elements such as wood alcohol, rubbing alcohol, butanol, amyl alcohol, cetyl alcohol, ethylene glycol, glycerin, poly vinyl alcohol (PVA), erythritol, xylitol, sorbitol, volemitol, allyl alcohol, geraniol, propargyl alcohol, inositol, menthol, poly vinyl alcohol, and computed Z_{eff} and N_{eff} for total photon interaction in photon energy range 1 keV to 100 GeV. The PVA is presently used as a radiation shielding for radiation protection, hard drives from data corruption, amino acid from oxidative damage in space flight [22]. The effective atomic number and electron densities have been compared with available possible experimental values at few photon energies [23, 24]. The effective atomic number of alcohols have been compared with water phantom, PMMA phantom, human organs, and tissues to explore possibilities for tissue substitutes. Kerma of alcohol relative to air (K_a) also have been computed for photon energy region 1 keV to 20 MeV. Computed photon interaction parameters for alcohols are found very useful for phantom and tissue substitute for dosimetric interest, shielding effectiveness, exposure and energy absorption build-up factors. In addition, the phantom equivalence compared with water

phantom, PMMA phantom, human organs and tissues is graphically shown for the interested photon energy regions.

COMPUTATIONAL METHOD

Direct method

Computations of the effective atomic number and electron densities of the alcohols for total gamma photon interaction have been carried out by practical formula [25]. The mass attenuation coefficients of the elements in our study have been obtained from WinXcom computer program [5, 6]. The atomic number and atomic mass of elements have been taken from atomic weight of elements [26]. The effective atomic number, Z_{Pleff}

$$Z_{\text{Pleff}} = \frac{\sum_i f_i A_i \frac{\mu}{\rho}_i}{\sum_i f_i \frac{A_i}{Z_i} \frac{\mu}{\rho}_i} \quad (1)$$

where f_i is the molar fraction in the mixture/compound, μ – the linear attenuation coefficient, ρ – the density, μ/ρ – the mass attenuation coefficient, A – the atomic weight, Z – the atomic number, and the ratio A/Z , between the atomic mass and the atomic number is approximately constant. The mass attenuation coefficients of individual elements are obtained from WinXcom program for photon energy 1 keV to 100 GeV.

The effective electron density is given by $N_{\text{eff}} = N_A Z/A$ which is generalized as

$$N_{\text{eff}} = N_A \frac{n Z_{\text{Pleff}}}{\sum_i n_i A_i} = N_A \frac{Z_{\text{Pleff}}}{\langle A \rangle} \quad (2)$$

where n_i is the number of atoms of the i^{th} constituent element, n – the total number of atoms in the molecule, and $\langle A \rangle$ – the average atomic mass of the alcohols.

Kerma of alcohols relative to air

Kinetic energy released per unit mass (kerma) is defined as the initial kinetic energy of all secondary charged particles liberated per unit mass at a point of interest by uncharged radiation [27, 28]. It is applicable to indirect ionizing radiation such as photons and neutrons and has the unit, J/kg = Gy, as the absorbed dose. Kerma is directly related to photon fluence and likelihood of interacting medium.

Kerma derived as let ψ [Jm^{-2}] is energy fluence of mono-energetic photon passing through A area, A of an absorber. The photon energy transferred from uncharged ionizing gamma radiation to charge particle in a volume over a short distance dx behind the area is

then $(\psi \mu_{en}) A dx$ where μ_{en} is mass energy-absorption coefficient. Since the mass in the volume with density ρ is $\rho A dx$, the kerma is

$$K = \frac{\psi \mu_{en} A dx}{\rho A dx} = \psi \frac{\mu_{en}}{\rho} \quad (3)$$

Therefore, the kerma is the product of the energy fluence and mass energy-absorption coefficient. Kerma of the alcohols relative to air can be derived as

$$K_a = \frac{K_{alcohol}}{K_{air}} = \frac{\frac{\mu_{en}}{\rho}_{alcohol}}{\frac{\mu_{en}}{\rho}_{air}} \quad (4)$$

Now the computation of kerma is calculation of mass energy-absorption coefficient, μ_{en}/ρ of alcohol and air by the following relation

$$\frac{\mu_{en}}{\rho} = \sum_i w_i \frac{\mu_{en}}{\rho}_i \quad (5)$$

where w_i and $(\mu_{en}/\rho)_i$ are the weight fraction and the mass energy-absorption coefficient of the i^{th} constituent element present in the alcohol. For any chemical compound, w_i is given by

$$w_i = \frac{n_i A_i}{\sum_i n_i A_i} \quad (6)$$

The values of $(\mu_{en}/\rho)_i$ have been taken from the compilation of Hubbell and Seltzer [29].

RESULTS AND DISCUSSION

Effective atomic numbers, Z_{Pleff} of the alcohols are given in tab. 1 along with effective atomic number based on XmuDat. In tab. 1 we have shown the ratio of Z_{Pleff} of alcohol to water and PMMA phantom for minimum and maximum values to understand the closeness of alcohols with phantoms at those energies. Comparison of Z_{Pleff} with experiment is given in tab. 2. The variation of Z_{Pleff} with the photon energy for alcohols is shown in figs. 1 and 2. The variation of N_{eff} with photon energy for alcohols is shown in fig. 3. Figure 4 gives variation of kerma values for alcohols relative to air, K_a in the photon energy region from 1 keV to 20 MeV. Figures 5 and 6 give the percentage deviation of Z_{Pleff} of alcohols relative to PMMA phantoms, water phantom for energy region 1 keV to 100 GeV, human organs and tissues in the photon energy region from 1 keV to 20 MeV.

Effective atomic number

The variation of Z_{Pleff} with gamma photon energy is shown in fig. 1. From the figure it is clear that the Z_{Pleff} of the alcohols varies with energy. In the energy range of 1 keV to 100 GeV, the variation of Z_{Pleff} with energy is mainly dominated by different photon interaction processes namely photoelectric absorption, Compton scattering and pair production. The

Table 1. Effective atomic numbers of the alcohols

Description	Formula/ Monomer	$(Z_{\text{eff}})_{\text{XmuDat}}$	Z_{Pleff}		$\frac{(Z_{\text{Pleff}})_{\text{alcohol}}}{(Z_{\text{Pleff}})_{\text{water}}}$		$\frac{(Z_{\text{Pleff}})_{\text{alcohol}}}{(Z_{\text{Pleff}})_{\text{PMMA}}}$	
			Min	Max	Min	Max	Min	Max
Wood alcohol	CH ₃ OH	6.80	3.0007	7.3884	0.90	0.93	0.83	1.06
Grain alcohol	C ₂ H ₅ OH	6.47	2.8895	7.0652	0.87	0.89	0.80	1.01
Rubbing alcohol	C ₃ H ₇ OH	–	2.8339	6.8619	0.85	0.86	0.79	0.99
Butanol	C ₄ H ₉ OH	6.15	2.8006	6.7222	0.84	0.84	0.78	0.97
Amyl alcohol	C ₅ H ₁₁ OH	–	2.7784	6.6204	0.83	0.83	0.77	0.95
Cetyl alcohol	C ₁₆ H ₃₃ OH	–	2.7064	6.2308	0.81	0.78	0.75	0.89
Ethylene glycol	C ₂ H ₄ (OH) ₂	–	3.4008	7.3943	1.02	0.93	0.94	1.06
Glycerin	C ₃ H ₅ (OH) ₃	6.95	3.5723	7.3962	1.07	0.93	0.99	1.06
PVA	C ₂ H ₄ O	6.62	3.4293	7.0739	1.03	0.89	0.95	1.02
Erythritol	C ₄ H ₆ (OH) ₄	–	3.6675	7.3972	1.10	0.93	1.02	1.06
Xylitol	C ₅ H ₇ (OH) ₅	–	3.7281	7.3978	1.12	0.93	1.04	1.06
Sorbitol	C ₆ H ₈ (OH) ₆	–	3.7701	7.3982	1.13	0.93	1.05	1.06
Volemitol	C ₇ H ₉ (OH) ₇	–	3.8008	7.3985	1.14	0.93	1.06	1.06
Allyl alcohol	C ₃ H ₅ OH	–	3.2006	6.8687	0.96	0.86	0.89	0.99
Geraniol	C ₁₀ H ₁₇ OH	–	2.9660	6.3629	0.89	0.80	0.82	0.91
Propargyl alcohol	C ₃ H ₃ OH	–	3.7507	6.8755	1.12	0.86	1.04	0.99
Inositol	C ₆ H ₆ (OH) ₆	–	4.0008	7.4002	1.20	0.93	1.11	1.06
Menthol	C ₁₀ H ₁₉ OH	–	2.8392	6.3602	0.85	0.80	0.79	0.91
Water	H ₂ O	7.51	3.3343	7.9818	1.00	1.00	0.93	1.15
PMMA	C ₅ H ₈ O ₂	6.56	3.6007	6.9646	0.90	0.93	1.00	1.00

variation in Z_{Pleff} is large below 100 keV where photoelectric process is dominant and the variation is almost constant between 0.3-3 MeV where the Compton scattering process is dominant and further above 100 MeV almost constant which is due to the pair production process. Therefore, the Z_{Pleff} value varies from 6.33 to 7.34 at 1 keV, varies from 2.7 to 4.0 at 1 MeV and varies from 2.92 to 4.33 at 10 GeV. It is needless to say that the higher values in the low energy region is due to photoelectric absorption process, the intermediate values in the medium energy region due to the Compton scattering and higher values in the high energy region is due to pair production process. All variations can be clearly explained by the Z dependence of total atomic cross-sections, thus Z_{Pleff} as Z^{4-5} for photoelectric absorption, Z for Compton scattering and Z^2 for pair production. It follows from the above that the photoelectric absorption cross-section gives higher weight to the high Z elements than the other processes and is proportional to Z^{4-5} which clearly explains the maximum values of Z_{Pleff} in the low energy region. In contrast, the Compton scattering cross-section is proportional to Z , giving less weight to the high Z elements than photoelectric absorption and pair production processes. Hence, the given alcohols have the low values of Z_{Pleff} in this energy region. These results are in good agreement with the experimental results as explained in next section. From figs. 1 and 2, it is clearly seen that Z_{Pleff} of the water phantom is higher than all the alcohols in photo absorption region whereas comparable in Compton and pair production regions. Also fig. 1(a)

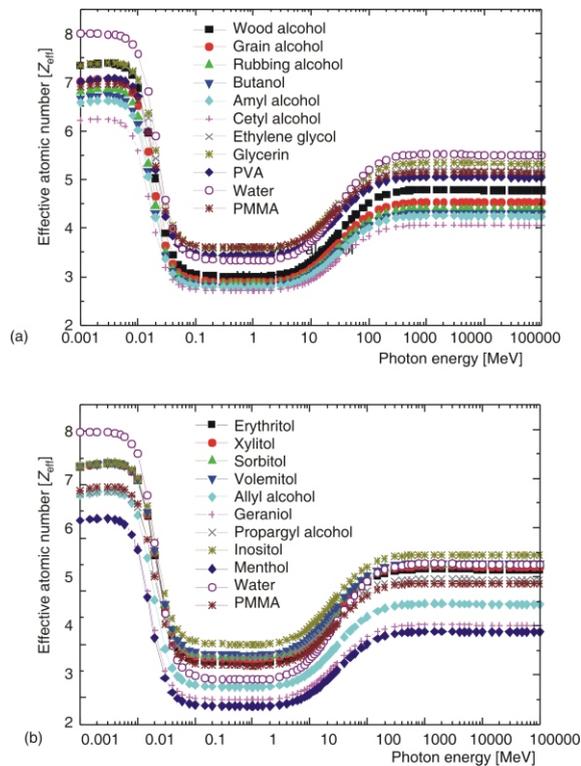


Figure 1. Effective atomic numbers of alcohols, water, and PMMA phantom

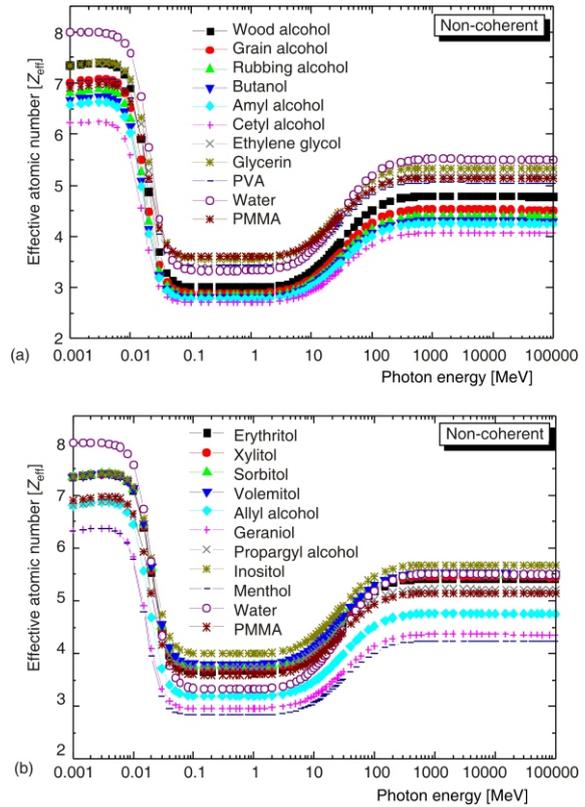


Figure 2. Effective atomic numbers for non-coherent of alcohols, water, and PMMA phantom

shows that Z_{Pleff} of wood alcohol is identical in the photon energy 1 keV to 100 GeV.

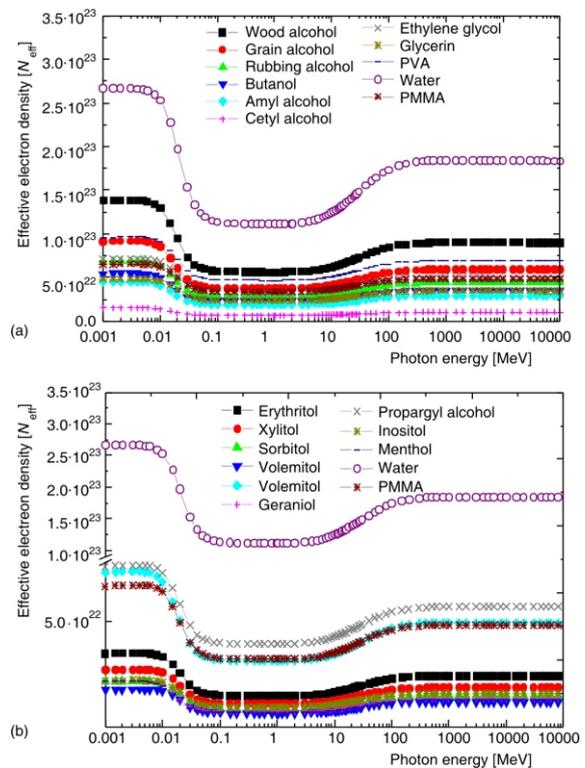


Figure 3. Effective electron densities of alcohols, water, and PMMA phantom

Effective electron densities

The N_{eff} of the alcohols containing low atomic number elements H, C, and O is shown in fig. 3. The Z_{Pleff} of the alcohols are found in the range of $1.5 \cdot 10^{22}$ to $2.7 \cdot 10^{23}$ electron/cm³ with minimum for C₁₆H₃₃OH. It is to be noted that the N_{eff} value is minimum for alcohol containing the maximum carbon and hydrogen atoms. The N_{eff} values follows variation of Z_{Pleff} values with lowest values in Compton scattering region and high values in photo-absorption and pair production region.

Comparison with experiments

Experimental data of effective atomic number of possible alcohols have been compared. The experimental values along with our calculated values are given in tab. 2. From the table we notice a good agreement be-

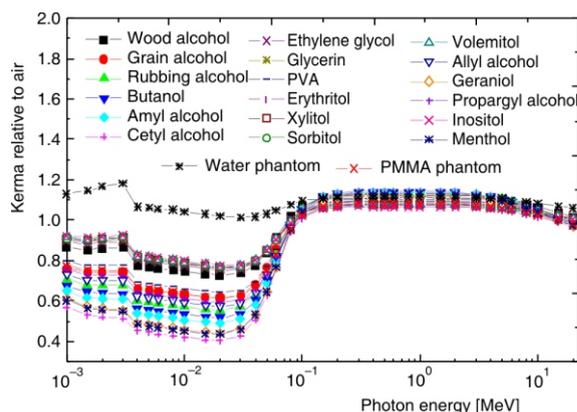


Figure 4. Energy dependency of kerma relative to air of alcohols

duction. K_a values of all the selected alcohols are in the range of 0.57 to 0.98 in the photon energy range from 1 keV to 80 keV. The K_a values of water are found of 1.02 to 1.18 in photon energy region of 1 keV to 80

Table 2. Comparison of effective atomic numbers with literature values

Alcohol	Literature*	Photon energy [keV]									
		54	59.54	81	123	356	511	662	1173	1274	1333
Wood alcohol	a	3.83	—	2.99	2.96	2.92	3.11	3.00	2.92	2.90	2.99
	c	3.21	3.17	3.08	3.03	3.00	3.02	3.00	2.99	2.99	3.00
Grain alcohol	a	3.00	—	3.02	2.8	2.7	2.91	3.85	2.85	2.85	—
	c	3.06	3.03	2.95	2.91	2.89	2.91	2.89	2.89	2.89	2.89
Butanol	b	2.92	0.09	—	—	—	—	—	—	—	—
	c	2.94	2.92	2.85	2.82	2.80	2.82	2.80	2.80	2.80	2.80
Glycerin	a	3.46	—	3.48	3.56	3.44	3.69	3.63	3.55	3.57	3.54
	b	3.81	0.12	—	—	—	—	—	—	—	—
	c	3.80	3.76	3.66	3.60	3.57	3.59	3.57	3.57	3.57	3.58

* (a) A. H. El-Kateb and A. S. Abdul-Hamid, 1991; (b) B. S. Sidhu *et al.*, 2012; (c) present computational work

tween calculated and experimental values of effective atomic numbers. From the comparison we notice that low energy photons have undergone the photoelectric absorption, medium energy photons photoelectric and Compton scattering and high energy photons the pair production process. To the best of our knowledge, there are no experimental data in the literature for photon energies above 1333 keV where in only pair production process is the major interaction process.

Kerma of alcohols

The variation of kerma relative to air (K_a) of the alcohols for photon energy 1 keV to 20 MeV is shown in fig. 4. It is to be noted that the K_a values of water are higher than alcohols in the entire photon energy region 1 keV to 20 MeV. We have found that the K_a values are equal to 1 at photon energy of ~80 keV. K_a variation with photon energy represents variation of effective atomic numbers in partial photon interaction process; photo absorption, Compton scattering, and pair pro-

duction. Above 100 keV the K_a values are in the range of 1 to 1.14. We have found that the K_a values are higher for poly-alcohols compared with mono-alcohol and water because the ¹⁶O weight fractions are larger. The K_a values of all the alcohols vary from 0.40 to 1.07 below 100 keV where photo absorption is dominating interaction process. In medium and high photon energy, K_a values are found to be more or less same.

Water and PMMA phantom substitute

Phantoms for calibration of the personal dosimeters are ISO, PMMA, and water phantoms, used as human tissue substitutes. It is found that the Z_{Pleff} of the alcohols are in range of the water and PMMA phantoms except slight variation for water phantom in photo-absorption region. Percentage deviation ($\Delta Z_{\text{Pleff}} = \text{Computed } Z_{\text{Pleff}} - \text{Phantom } Z_{\text{Pleff}} / \text{phantom } Z_{\text{Pleff}}$) of the alcohols relative to phantom is shown in fig. 5(a, b). The Z_{Pleff} for PMMA phantom for pho-

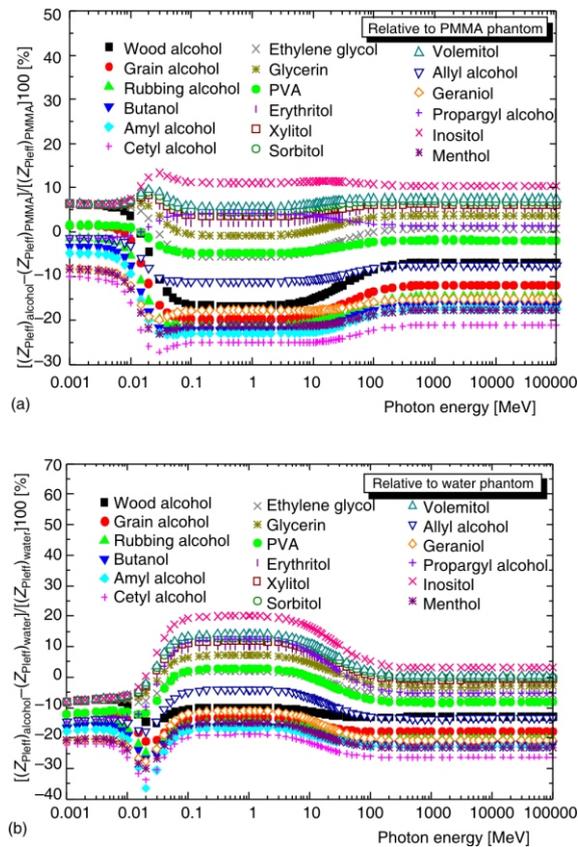


Figure 5. ΔZ_{Pleff} [%] of alcohols relative PMMA and water phantoms

ton energy range 1 keV to 100 GeV are found of -24.88% to $+11.50\%$ whereas -36.45% to $+19.98\%$ for water phantom. It is to be noted that the Z_{Pleff} variation is very large in photon energy 0.008 to 0.03 MeV similar to photoelectric absorption. We found that ΔZ_{Pleff} value for the ethylene glycol, glycerin and PVA relative to PMMA phantom are near to zero in photon energy from 10 keV to 10 MeV therefore these alcohols are substitute of PMMA phantom. In energy range 100 MeV to 100 GeV, propargyl alcohol is most suitable substitute for PMMA phantom. The suitable substitute for the water phantom is found erythritol alcohol in the photon energy region, of 100 keV to 15 MeV. Figure 5(b) shows that PVA is water phantom substitute in energy region of 100 keV to 100 GeV.

Human organ and tissues substitute

Human organs and tissues substitutes have been compiled by White [30]. The Z_{Pleff} of alcohols have been compared with water and PMMA phantoms in the earlier section. Similarly we have investigated for human organs and tissue such as skeleton muscle, soft tissue, lung tissue, adipose tissue, blood, brain, breast tissue, eye lens, ovary, testis, and soft tissue 4-compartment [2] by calculating the percentage deviation

of the ΔZ_{Pleff} (%) of the alcohols as shown in fig. 6(a-h).

Percentage deviations ($\Delta Z_{Pleff} = \text{computed } Z_{Pleff} - \text{human organs and tissue } Z_{Pleff} / \text{human organs and tissue } Z_{Pleff} \times 100$) of the alcohols are found within range of -40% to $+30\%$ for photon energy region of 1 keV to 20 MeV.

Figure 6(a-f) show that glycerin, PVA and ethylene glycol are nearest skellton muscle, soft tissue, lung tissue, blood, and brain substitute in photon energy region, 0.1 to 10 MeV whereas glycerin is only possible substitute in energy above 10 MeV.

Figure 6(d) shows that PVA and allyl alcohol are adipose tissue substitute in photon energy of 1 keV to 0.01 MeV whereas allyl alcohol and wood alcohols are nearest adipose tissue equivalent in photon energy of 0.1 MeV to 20 MeV.

Figure 6(g) shows that in low photon energy of 1 keV to 0.01 MeV, wood alcohol, inositol, volemitol, xylitol, glycerin, ethylene glycol, PVA, and erythritol are breast tissue substitute whereas ethylene glycol and PVA are breast substitute in remaining energy region.

Figure 6(h) shows that glycerine is eye lens substitute in photon energy of 0.1 to 20 MeV.

Similarly it was found that glycerin may be substitute for ovary, testis, and soft tissue (4-compartment) in photon energy region of 0.1 to 20 MeV.

CONCLUSIONS

The present computation of Z_{Pleff} and N_{eff} are based on atomic photon-interaction cross-sections. In the present approximation, Z_{Pleff} and N_{eff} are independent of any chemical bonding effects of the alcohols. A much larger and higher-dimensional database would be required to accommodate molecular and other matrix environments of the target atom [1]. Careful experiments would be required to study any possible chemical bonding environment on photon-interaction cross-sections and effective atomic numbers of the alcohols. By our study, we conclude that:

the effective atomic number and the corresponding effective electron density of eighteen alcohols have been calculated in photon energy region from 1 keV to 100 GeV,

three energy regions are approximately $E < 0.01$ MeV, $0.05 \text{ MeV} < E < 5 \text{ MeV}$, and $E > 200 \text{ MeV}$, the main photon-interaction processes in these regions are photoelectric absorption, incoherent Compton scattering and pair production, respectively,

the maximum values of effective atomic number and electron densities for total and non-coherent scattering are found in the low-energy range of photoelectric absorption region,

the minimum values of effective atomic number and electron densities are found at intermediate

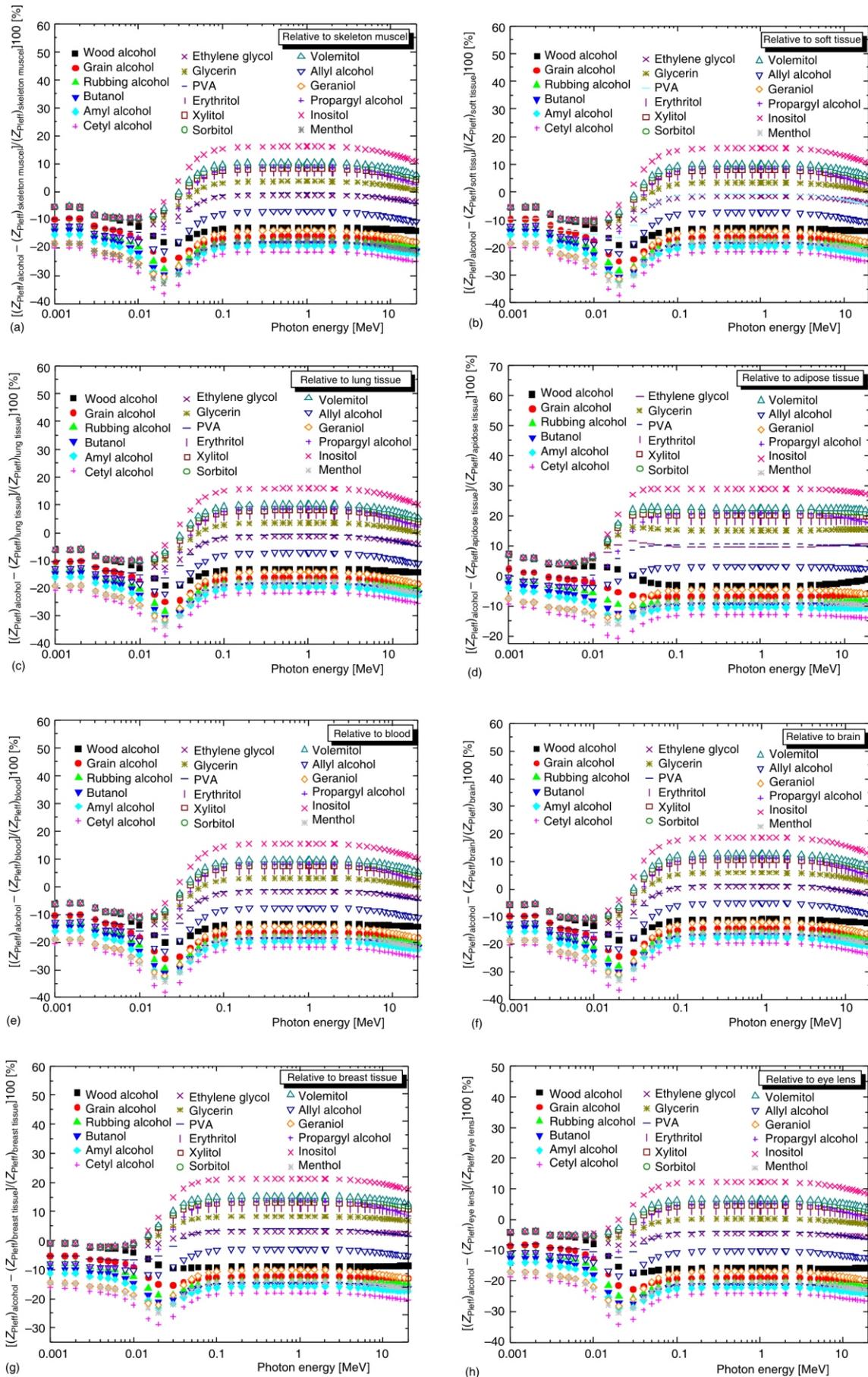


Figure 6. ΔZ_{Pieff} [%] of alcohols relative to human organs and tissues

energies, typically $0.05 \text{ MeV} < E < 5 \text{ MeV}$, where Compton scattering is dominant, the single values of the effective atomic number and the electron density provided by the program XMuDat are found between minimum and maximum values calculated, the poly-alcohols are having large kerma values compared with mono-alcohol in photo absorption region, kerma calculation and equivalence analysis of alcohols with water phantom, PMMA phantom, human organs and tissues have thrown light for phantom and tissue substitutes useful in radiation physics, dosimetric interest, medical applications and radio diagnosis, and ethylene glycol, glycerin and PVA, allyl alcohol and wood alcohols are very useful alcohols for tissue substitute in radiation physics and radiobiology.

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AUTHOR CONTRIBUTIONS

The idea for study of new dosimetric material was put forward by V. P. Singh, theoretical calculations were done by V. P. Singh, and analysis and discussion was carried out by V. P. Singh and N. M. Badiger. The manuscript was written and figures were prepared by V. P. Singh.

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**СТУДИЈА О ЕФЕКТИВНИМ АТОМСКИМ БРОЈЕВИМА И ГУСТИНАМА
ЕЛЕКТРОНА, КЕРМИ У АЛКОХОЛИМА, ФАНТОМУ, ЉУДСКИМ
ОРГАНИМА И ТКИВНИМ ЕКВИВАЛЕНТИМА**

За осамнаест врста алкохола, као што су метанол CH_3OH , етанол $\text{C}_2\text{H}_5\text{OH}$, изопропил алкохол $\text{C}_3\text{H}_7\text{OH}$, бутанол $\text{C}_4\text{H}_9\text{OH}$, амил алкохол $\text{C}_5\text{H}_{11}\text{OH}$, цетил алкохол $\text{C}_{16}\text{H}_{33}\text{OH}$, етилен гликол $\text{C}_2\text{H}_4(\text{OH})_2$, глицерин $\text{C}_3\text{H}_5(\text{OH})_3$, поливинил аcohol $\text{C}_2\text{H}_4\text{O}$, еритритол $\text{C}_4\text{H}_6(\text{OH})_4$, ксилитол $\text{C}_5\text{H}_7(\text{OH})_5$, сорбитол $\text{C}_6\text{H}_8(\text{OH})_6$, волемитол $\text{C}_7\text{H}_9(\text{OH})_7$, алил алкохол $\text{C}_3\text{H}_5\text{OH}$, гераниол $\text{C}_{10}\text{H}_{17}\text{OH}$, пропаргил алкохол $\text{C}_3\text{H}_3\text{OH}$, инозитол $\text{C}_6\text{H}_6(\text{OH})_6$ и ментол $\text{C}_{10}\text{H}_{19}\text{OH}$, израчунати су ефективни атомски број Z_{Peff} и густина електрона у опсегу енергија фотона од 1 keV до 1 GeV. Извршено је упоређивање процењених и експерименталних вредности, где год је било могуће. Поређење Z_{Peff} алкохола са воденим фантомом и фантомом од плексигласа РММА, показује да су етилен гликол, глицерин и поливинил алкохол замена за плексиглас РММА фантоме, док се поливинил алкохол може користити и као замена за водени фантом. Извршено је и поређење са људским органима и ткивима. За етилен гликол, глицерин, поливинил алкохол, алил алкохол и метанол утврђено је да се могу користити као замена за људско ткиво за већину органа. Керма, која је производ флуенса енергије и масеног коефицијента апсорпције, израчуната је у опсегу енергија од 1 keV до 20 MeV за разматране алкохоле. Резултати показују да је керма изнад 100 keV мање-више независна од енергије.

Кључне речи: алкохол, фантом, ефективни атомски број, људско ткиво, зама зрачење, керма