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Research Article

A theoretical evaluation on radiation shielding features of Van-Erciş and Rize-İkizdere (Türkiye) obsidians by using Phy-X/PSD code

Zeynep AYGUN[1]*, Murat AYGUN[2]

[1]*Bitlis Eren University, Vocational School of Technical Sciences, Bitlis, 13000, Türkiye*
[2]*Bitlis Eren University, Faculty of Science and Arts, Department of Physics, Bitlis, 13000, Türkiye*

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ABSTRACT

Obsidians are naturally occurring glassy volcanic rocks which have great interest and are commonly preferred in engineering, medical and nuclear applications. In the present study, we aimed to determine the radiation attenuation parameters of Van-Erciş and Rize-Ikizdere obsidians in Türkiye in order to examine the radiation shielding potentials of the samples. The parameters were calculated in the range of 4keV-100GeV incident photon energies by Phy-X/PSD software. In order to make a meaningful evaluation about the shielding features of the samples, we compared the obtained mass and linear attenuation coefficients of the obsidians with those of a widely used shielding material, ordinary concrete. It was concluded that Ikizdere obsidian has higher shielding potential compared to Erciş obsidian, and both Ikizdere obsidian and Erciş obsidian have more shielding ability than that of ordinary concrete.

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INTRODUCTION

Radiation protection and hence, radiation shielding materials have great interest due to the increase of radiation applications in people's daily lives. Many studies were carried out for determining shielding properties of different materials before [1-6]. Obsidian is a natural glassy structure associated to volcanic rocks. These glassy volcanic rocks are commonly preferred in engineering, medical and nuclear applications. It is important to learn if these kind of widely used natural materials have radiation shielding features or not. There are many volcanic regions in the world and therefore many obsidian types that vary according to the regional differences. Erciş and Ikızdere obsidians are the two of them in Türkiye. Erciş-Van obsidians are located in 20 km Northern of Van in Northeast of Anatolian plate [7]. Ikizdere-Rize obsidians covers around 10 km2 north-northeast of Ikizdere region. The obsidians were formed during Upper Pliocene Pleistocene period in the last phase of volcanism [8].

***Corresponding author.**
*E-mail address: zeynep.yarbasi@gmail.com, zaygun@beu.edu.tr

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There are some softwares in the literature such as XCOM [9], GEANT4 [10], WinXCOM [11,12], and XMuDat [13] used for calculation of MAC values for elements, compounds and mixtures. We preferred recently reported and widely used Phy-X/PSD code which can calculate quickly and accurately all specified shielding parameters for different materials in the continuous energy range [14]. In this study, we aimed to calculate radiation attenuation parameters which give significant knowledge about the radiation shielding abilities of the materials. For this purpose, we determined the mass attenuation coefficient (MAC), linear attenuation coefficient (LAC), effective atomic number (Zeff), half-value layer (HVL), tenth-value layer (TVL), total atomic cross section (ACS), total electronic cross section (ECS), effective conductivity (Ceff) and effective electron number (Neff) in a wide photon energy range (4keV-100GeV) by Phy-X/PSD code. It is also aimed to compare the MAC and LAC values of the obsidians with those of ordinary concrete which is a commonly used shielding material.

THEORY

In this study, Erciş obsidians and Ikizdere obsidians were obtained from Van-Erciş Ulupamir Village and Rize-Ikizdere Büyükyayla region, respectively. Plaques were cut from the rocks and thin sections were prepared for the analysis of chemical compositions. Chemical compositions of the samples were determined by X-ray fluorescence technique and the used compositions were taken from literature [7,15].

Phy-X/PSD software, which is recently developed to determine the radiation shielding parameters of different materials, was used in the calculation. Calculation process is started by defining the chemical composition and the density of the material in the program. In the software, the material composition can be entered as mole fraction or weight fraction. The parameters are determined in a wide energy range by selecting the energy sources (^{22}Na, ^{55}Fe, ^{60}Co, ^{109}Cd, ^{131}I, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{241}Am and the K-shell energies of Cu, Rb, Mo, Ag, Ba and Tb elements) [14]. Lastly, the desired shielding parameters are selected for the purpose and the parameters used in calculation process are given with their formulas below.

The MAC is a quantity that defines the interaction possibility between gamma photons and the mass per unit area for a particular medium and can be calculated by the Beer–Lambert formulated as:

$$I = I_0 e^{-\mu t} \tag{1}$$

$$\mu_m = \frac{\mu}{\rho} = \ln(I_0/I)/\rho t = ln(I_0/I)/t_m \tag{2}$$

where I_0 and I are incident and attenuated photon intensities, ρ (g/cm^3) is the density of material, μ_m(cm^2/g) and μ(cm^{-1}) are mass and linear attenuation coefficients, t_m (g/cm^2) and t (cm) are sample mass thickness (the mass per unit area) and the thickness, respectively.

If the sample has various elements, we can write the total mass attenuation coefficient for any compound as follows [16];

$$\mu/\rho = \Sigma_i w_i\,(\mu/\rho)_i \tag{3}$$

where w_i and $(\mu/\rho)_i$ are the weight fraction and the mass attenuation coefficient of the ith constituent element, respectively.

The total atomic cross-section (σ_a) for any sample can be calculated using the equation formulated as;

$$ACS = \sigma_a = \frac{N}{N_A}(\mu/\rho) \tag{4}$$

where N_A and N respectively are the Avogadro's number and the atomic mass of materials.

The total electronic cross-section (σ_e) is formulated the following equation [17];

$$ECS = \sigma_e = \frac{\sigma_a}{Z_{eff}} \tag{5}$$

By using the Equations (4) and (5), we can find the effective atomic number, Z_{eff}, of the material as follows;

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \tag{6}$$

We can calculate the effective electron number, N_{eff}, as follows [18],

$$N_{eff} = \frac{\mu_m}{\sigma_e} \tag{7}$$

HVL and TVL are the thicknesses parameters that are the used to reduce the radiation intensities by one half and one tenth, respectively. MFP is the average distance at which a photon travels through the material between two interactions. The μ is used to obtain the parameters given by

$$HVL = \frac{In(2)}{\mu} \tag{8}$$

$$MFP = \frac{1}{\mu} \tag{9}$$

$$HVL = \frac{In10}{\mu} \tag{10}$$

Effective conductivity (C_{eff}) of materials can be given by the following equation [19]:

Table 1. Chemical compositions of EO and IO.

Obsidian	SiO_2	Al_2O_3	TiO_2	MnO	CaO	Fe_2O_3	K_2O	Na_2O	MgO	P_2O_5
Erciş	77.13	15.40	0.51	0.07	0.34	1.07	3.33	2.15	-	-
İkizdere	75.41	13.87	0.15	0.05	0.89	1.25	4.79	3.99	0.11	0.02

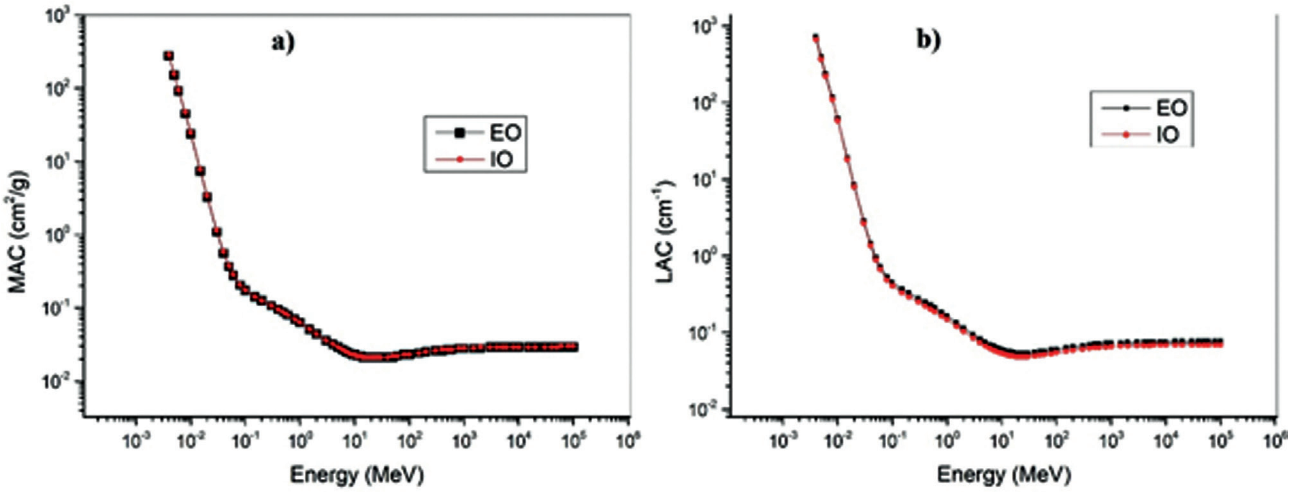

Figure 1. The changes of MAC (a) and LAC (b) as a function of incident photon energy.

$$C_{eff} = \frac{N_{eff}\rho e^2 \tau}{m_e} 10^3 \quad (11)$$

where m_e (kg) and e (C) are mass and charge of electron, respectively.

RESULTS AND DISCUSSION

The chemical compositions of Ikizdere obsidian (IO) and Ercis obsidian (EO) are obtained from literature and are given in Table 1 [7,15]. The theoretically calculated radiation attenuation parameters of the EO and IO are listed in Table 2-3, respectively.

Variations of the calculated MAC values of the obsidians versus photon energies (4keV-100GeV) are shown in Fig. 1(a). In the low energy region (1-100keV) where the photoelectric process is predominant, MAC values decreased sharply with increasing energy. In the intermediate energy region (100keV–5MeV) where the Compton scattering is dominant, MAC values slightly changed. Above 5MeV, the Pair production process starts and an increase in MAC values was observed with increasing energy [1,20].

LAC is an important parameter for defining the photon-matter interaction, but it is not sufficient. The value of LAC depends on both MAC and density of compound. Dependence of the calculated LAC values versus photon energies (4keV-100GeV) is shown in Fig. 1(b). Differences of LAC values are greater than those of MAC values depending on the density effect. It was obtained that the MAC and LAC values of both obsidians were very near to each other for the given energies. In low energies, MAC values of IO are slightly bigger than those of EO, it can be said that IO has more absorption feature than EO. It was determined that the shielding potentials of the both EO and IO are more than the shielding potential of ordinary concrete (OC) [21], when the obtained MAC and LAC values of the obsidians are compared with those of OC (Table 4).

The interaction possibility of per atom and per electron in a unit volume of any material is given by ACS and ESC, respectively. Changing of ACS and ECS values as a function of incident photon energies are given in Fig. 2(a-b). The obsidian with higher ACS and ECS values can be defined as better shielding obsidian. According to the obtained results for ACS and ECS parameters of the samples, the shielding potential of the IO is slightly higher than the EO.

The HVL and TVL parameters give the information about the penetration ability of the radiations in materials. HVL, TVL and MFP parameters changing as a function of incident photon energies are given in Fig 3(a-c). In the mid-energy region where Compton scattering is dominant, most photons are more likely to be scattered. Therefore, their absorption probabilities are lower and hence thicker

Table 2. Photon attenuation parameters of EO between the energies of 4keV and 100GeV.

Energy	MAC	LAC	HVL	TVL	MFP	Neff	Ceff	ACS	ECS	Zeff
MeV	cm²/g	1/cm	cm	cm	cm	electrons/g	S/m	cm²/g	cm²/g	
4.00E-03	275.091	715.236	0.001	0.003	0.001	3.71E+23	6.96E+08	9.46E-21	7.42E-22	12.76
5.00E-03	151.300	393.380	0.002	0.006	0.003	3.77E+23	7.07E+08	5.20E-21	4.02E-22	12.95
6.00E-03	90.599	235.559	0.003	0.010	0.004	3.78E+23	7.10E+08	3.12E-21	2.39E-22	13.02
8.00E-03	44.610	115.986	0.006	0.020	0.009	4.02E+23	7.55E+08	1.53E-21	1.11E-22	13.84
1.00E-02	23.568	61.278	0.011	0.038	0.016	4.05E+23	7.61E+08	8.11E-22	5.81E-23	13.94
1.50E-02	7.327	19.051	0.036	0.121	0.052	4.08E+23	7.66E+08	2.52E-22	1.80E-23	14.03
2.00E-02	3.226	8.387	0.083	0.275	0.119	4.06E+23	7.62E+08	1.11E-22	7.95E-24	13.96
3.00E-02	1.084	2.818	0.246	0.817	0.355	3.92E+23	7.36E+08	3.73E-23	2.77E-24	13.48
4.00E-02	0.556	1.445	0.480	1.594	0.692	3.72E+23	6.98E+08	1.91E-23	1.49E-24	12.79
5.00E-02	0.365	0.948	0.731	2.428	1.054	3.53E+23	6.63E+08	1.25E-23	1.03E-24	12.14
6.00E-02	0.278	0.723	0.959	3.186	1.384	3.38E+23	6.35E+08	9.56E-24	8.22E-25	11.63
8.00E-02	0.204	0.531	1.306	4.337	1.884	3.20E+23	6.01E+08	7.02E-24	6.37E-25	11.02
1.00E-01	0.173	0.451	1.537	5.106	2.218	3.11E+23	5.85E+08	5.96E-24	5.57E-25	10.71
1.50E-01	0.141	0.367	1.890	6.277	2.726	3.03E+23	5.69E+08	4.85E-24	4.65E-25	10.43
2.00E-01	0.125	0.326	2.125	7.060	3.066	3.01E+23	5.65E+08	4.31E-24	4.17E-25	10.35
3.00E-01	0.107	0.278	2.490	8.273	3.593	3.00E+23	5.62E+08	3.68E-24	3.57E-25	10.30
4.00E-01	0.095	0.248	2.796	9.289	4.034	2.99E+23	5.61E+08	3.28E-24	3.19E-25	10.29
5.00E-01	0.087	0.226	3.070	10.199	4.429	2.99E+23	5.61E+08	2.99E-24	2.91E-25	10.28
6.00E-01	0.080	0.209	3.324	11.041	4.795	2.99E+23	5.61E+08	2.76E-24	2.68E-25	10.28
8.00E-01	0.070	0.183	3.789	12.586	5.466	2.99E+23	5.61E+08	2.42E-24	2.36E-25	10.27
1.00E+00	0.063	0.164	4.216	14.007	6.083	2.99E+23	5.61E+08	2.17E-24	2.12E-25	10.27
1.50E+00	0.051	0.134	5.178	17.201	7.470	2.99E+23	5.61E+08	1.77E-24	1.72E-25	10.27
2.00E+00	0.044	0.115	6.004	19.944	8.662	2.99E+23	5.61E+08	1.53E-24	1.49E-25	10.28
3.00E+00	0.036	0.094	7.370	24.484	10.633	3.00E+23	5.63E+08	1.24E-24	1.21E-25	10.31
4.00E+00	0.032	0.082	8.449	28.066	12.189	3.01E+23	5.65E+08	1.09E-24	1.05E-25	10.35
5.00E+00	0.029	0.074	9.314	30.940	13.437	3.02E+23	5.67E+08	9.84E-25	9.47E-26	10.39
6.00E+00	0.027	0.069	10.008	33.246	14.439	3.03E+23	5.69E+08	9.16E-25	8.78E-26	10.43
7.00E+00	0.025	0.066	10.570	35.111	15.249	3.04E+23	5.71E+08	8.67E-25	8.29E-26	10.47
8.00E+00	0.024	0.063	11.027	36.631	15.908	3.05E+23	5.73E+08	8.31E-25	7.92E-26	10.50
9.00E+00	0.023	0.061	11.397	37.861	16.443	3.06E+23	5.75E+08	8.04E-25	7.63E-26	10.54
1.00E+01	0.023	0.059	11.701	38.871	16.882	3.07E+23	5.77E+08	7.84E-25	7.41E-26	10.57
1.10E+01	0.022	0.058	11.953	39.707	17.245	3.08E+23	5.78E+08	7.67E-25	7.24E-26	10.60
1.20E+01	0.022	0.057	12.160	40.394	17.543	3.09E+23	5.80E+08	7.54E-25	7.10E-26	10.62
1.30E+01	0.022	0.056	12.331	40.963	17.790	3.10E+23	5.81E+08	7.44E-25	6.98E-26	10.65
1.40E+01	0.021	0.056	12.471	41.426	17.991	3.10E+23	5.82E+08	7.35E-25	6.89E-26	10.67
1.50E+01	0.021	0.055	12.583	41.800	18.153	3.11E+23	5.84E+08	7.29E-25	6.81E-26	10.69
1.60E+01	0.021	0.055	12.674	42.103	18.285	3.11E+23	5.85E+08	7.23E-25	6.75E-26	10.71
1.80E+01	0.021	0.054	12.808	42.549	18.479	3.13E+23	5.87E+08	7.16E-25	6.66E-26	10.75
2.00E+01	0.021	0.054	12.890	42.819	18.596	3.13E+23	5.88E+08	7.11E-25	6.60E-26	10.78
2.20E+01	0.021	0.054	12.934	42.966	18.660	3.14E+23	5.90E+08	7.09E-25	6.56E-26	10.81
2.40E+01	0.021	0.054	12.951	43.024	18.685	3.15E+23	5.91E+08	7.08E-25	6.54E-26	10.83
2.60E+01	0.021	0.054	12.952	43.024	18.685	3.15E+23	5.92E+08	7.08E-25	6.52E-26	10.85
2.80E+01	0.021	0.054	12.936	42.971	18.662	3.16E+23	5.93E+08	7.09E-25	6.52E-26	10.87
3.00E+01	0.021	0.054	12.910	42.887	18.625	3.16E+23	5.94E+08	7.10E-25	6.52E-26	10.88

Energy	MAC	LAC	HVL	TVL	MFP	Neff	Ceff	ACS	ECS	Zeff
MeV	cm²/g	1/cm	cm	cm	cm	electrons/g	S/m	cm²/g	cm²/g	
4.00E+01	0.021	0.055	12.705	42.205	18.329	3.18E+23	5.98E+08	7.22E-25	6.59E-26	10.95
5.00E+01	0.021	0.056	12.460	41.392	17.976	3.19E+23	6.00E+08	7.36E-25	6.70E-26	10.99
6.00E+01	0.022	0.057	12.232	40.633	17.647	3.20E+23	6.01E+08	7.50E-25	6.81E-26	11.01
8.00E+01	0.023	0.059	11.838	39.327	17.079	3.21E+23	6.03E+08	7.74E-25	7.01E-26	11.05
1.00E+02	0.023	0.060	11.535	38.320	16.642	3.22E+23	6.04E+08	7.95E-25	7.18E-26	11.06
1.50E+02	0.024	0.063	11.014	36.587	15.889	3.22E+23	6.05E+08	8.32E-25	7.51E-26	11.08
2.00E+02	0.025	0.065	10.692	35.518	15.425	3.23E+23	6.05E+08	8.58E-25	7.73E-26	11.09
3.00E+02	0.026	0.067	10.307	34.239	14.870	3.23E+23	6.06E+08	8.90E-25	8.02E-26	11.10
4.00E+02	0.026	0.069	10.084	33.497	14.548	3.23E+23	6.06E+08	9.09E-25	8.19E-26	11.10
5.00E+02	0.027	0.070	9.937	33.010	14.336	3.23E+23	6.06E+08	9.23E-25	8.31E-26	11.10
6.00E+02	0.027	0.070	9.832	32.662	14.185	3.23E+23	6.06E+08	9.33E-25	8.40E-26	11.10
8.00E+02	0.028	0.072	9.691	32.192	13.981	3.23E+23	6.06E+08	9.46E-25	8.52E-26	11.10
1.00E+03	0.028	0.072	9.600	31.889	13.849	3.23E+23	6.06E+08	9.55E-25	8.60E-26	11.10
1.50E+03	0.028	0.073	9.468	31.453	13.660	3.23E+23	6.06E+08	9.68E-25	8.72E-26	11.10
2.00E+03	0.028	0.074	9.398	31.219	13.558	3.23E+23	6.06E+08	9.76E-25	8.79E-26	11.10
3.00E+03	0.029	0.074	9.320	30.959	13.445	3.23E+23	6.06E+08	9.84E-25	8.86E-26	11.10
4.00E+03	0.029	0.075	9.276	30.813	13.382	3.23E+23	6.06E+08	9.88E-25	8.90E-26	11.10
5.00E+03	0.029	0.075	9.251	30.731	13.346	3.23E+23	6.06E+08	9.91E-25	8.93E-26	11.10
6.00E+03	0.029	0.075	9.230	30.662	13.316	3.23E+23	6.06E+08	9.93E-25	8.95E-26	11.10
8.00E+03	0.029	0.075	9.207	30.586	13.283	3.23E+23	6.06E+08	9.96E-25	8.97E-26	11.10
1.00E+04	0.029	0.075	9.191	30.530	13.259	3.23E+23	6.06E+08	9.98E-25	8.99E-26	11.10
1.50E+04	0.029	0.076	9.171	30.465	13.231	3.23E+23	6.06E+08	1.00E-24	9.00E-26	11.10
2.00E+04	0.029	0.076	9.159	30.425	13.213	3.23E+23	6.06E+08	1.00E-24	9.02E-26	11.10
3.00E+04	0.029	0.076	9.145	30.380	13.194	3.23E+23	6.06E+08	1.00E-24	9.03E-26	11.10
4.00E+04	0.029	0.076	9.139	30.359	13.185	3.23E+23	6.06E+08	1.00E-24	9.04E-26	11.10
5.00E+04	0.029	0.076	9.136	30.350	13.181	3.23E+23	6.06E+08	1.00E-24	9.04E-26	11.10
6.00E+04	0.029	0.076	9.133	30.338	13.176	3.23E+23	6.06E+08	1.00E-24	9.04E-26	11.10
8.00E+04	0.029	0.076	9.130	30.330	13.172	3.23E+23	6.06E+08	1.00E-24	9.05E-26	11.10
1.00E+05	0.029	0.076	9.127	30.318	13.167	3.23E+23	6.06E+08	1.00E-24	9.05E-26	11.10

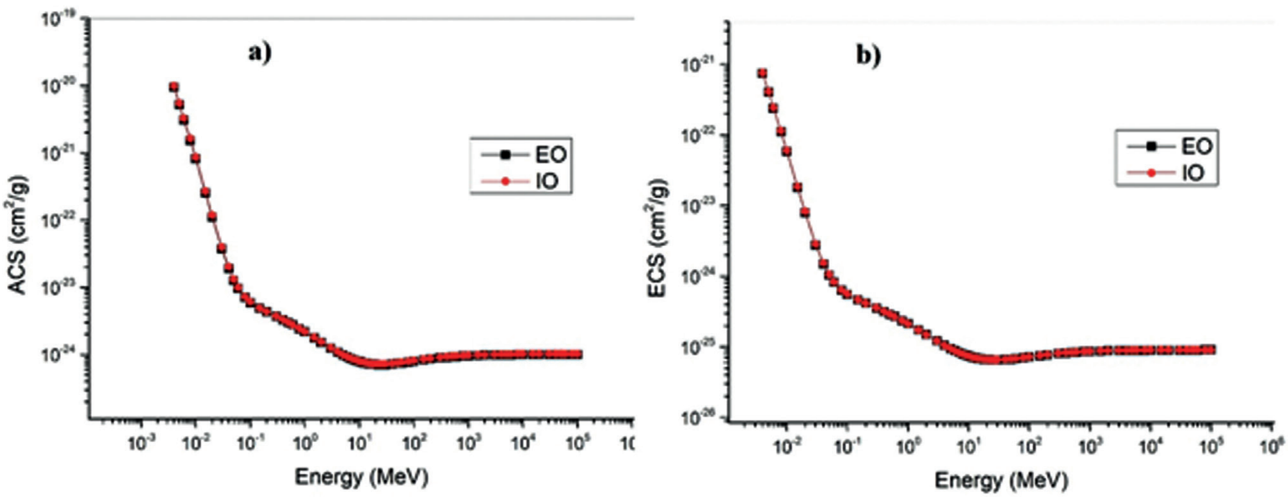

Figure 2. The variations of ACS (a) and ECS (b) as a function of incident photon energy.

Table 3. Photon attenuation parameters of IO between the energies of 4keV and 100GeV.

Energy	MAC	LAC	HVL	TVL	MFP	Neff	Ceff	ACS	ECS	Zeff
MeV	cm²/g	1/cm	cm	cm	cm	electrons/g	S/m	cm²/g	cm²/g	
4.00E-03	284.551	668.694	0.001	0.003	0.001	3.74E+23	6.35E+08	9.88E-21	7.60E-22	12.99
5.00E-03	156.927	368.778	0.002	0.006	0.003	3.80E+23	6.44E+08	5.45E-21	4.13E-22	13.18
6.00E-03	94.114	221.168	0.003	0.010	0.005	3.82E+23	6.48E+08	3.27E-21	2.46E-22	13.26
8.00E-03	46.973	110.387	0.006	0.021	0.009	4.08E+23	6.92E+08	1.63E-21	1.15E-22	14.16
1.00E-02	24.868	58.440	0.012	0.039	0.017	4.11E+23	6.97E+08	8.63E-22	6.05E-23	14.27
1.50E-02	7.750	18.213	0.038	0.126	0.055	4.14E+23	7.02E+08	2.69E-22	1.87E-23	14.37
2.00E-02	3.412	8.019	0.086	0.287	0.125	4.12E+23	6.99E+08	1.18E-22	8.28E-24	14.30
3.00E-02	1.141	2.681	0.259	0.859	0.373	3.98E+23	6.75E+08	3.96E-23	2.87E-24	13.81
4.00E-02	0.580	1.363	0.508	1.689	0.733	3.77E+23	6.40E+08	2.01E-23	1.54E-24	13.09
5.00E-02	0.377	0.887	0.782	2.597	1.128	3.57E+23	6.06E+08	1.31E-23	1.06E-24	12.40
6.00E-02	0.285	0.670	1.034	3.436	1.492	3.42E+23	5.80E+08	9.90E-24	8.35E-25	11.86
8.00E-02	0.207	0.487	1.423	4.728	2.053	3.22E+23	5.47E+08	7.19E-24	6.43E-25	11.19
1.00E-01	0.175	0.411	1.686	5.600	2.432	3.13E+23	5.30E+08	6.07E-24	5.60E-25	10.85
1.50E-01	0.142	0.333	2.084	6.924	3.007	3.04E+23	5.15E+08	4.91E-24	4.66E-25	10.54
2.00E-01	0.126	0.295	2.348	7.801	3.388	3.01E+23	5.11E+08	4.36E-24	4.17E-25	10.45
3.00E-01	0.107	0.252	2.755	9.152	3.974	2.99E+23	5.08E+08	3.72E-24	3.58E-25	10.39
4.00E-01	0.095	0.224	3.094	10.279	4.464	2.99E+23	5.07E+08	3.31E-24	3.19E-25	10.38
5.00E-01	0.087	0.204	3.398	11.286	4.902	2.99E+23	5.07E+08	3.01E-24	2.91E-25	10.37
6.00E-01	0.080	0.188	3.678	12.219	5.307	2.99E+23	5.07E+08	2.78E-24	2.68E-25	10.37
8.00E-01	0.070	0.165	4.193	13.930	6.050	2.99E+23	5.07E+08	2.44E-24	2.36E-25	10.36
1.00E+00	0.063	0.149	4.667	15.504	6.733	2.98E+23	5.06E+08	2.19E-24	2.12E-25	10.36
1.50E+00	0.051	0.121	5.731	19.038	8.268	2.99E+23	5.06E+08	1.79E-24	1.72E-25	10.36
2.00E+00	0.044	0.104	6.644	22.072	9.586	2.99E+23	5.07E+08	1.54E-24	1.49E-25	10.37
3.00E+00	0.036	0.085	8.153	27.084	11.762	3.00E+23	5.09E+08	1.26E-24	1.21E-25	10.41
4.00E+00	0.032	0.074	9.341	31.029	13.476	3.01E+23	5.11E+08	1.10E-24	1.05E-25	10.45
5.00E+00	0.029	0.067	10.291	34.187	14.847	3.02E+23	5.13E+08	9.95E-25	9.48E-26	10.49
6.00E+00	0.027	0.063	11.052	36.715	15.945	3.03E+23	5.15E+08	9.26E-25	8.79E-26	10.53
7.00E+00	0.025	0.059	11.666	38.754	16.831	3.05E+23	5.17E+08	8.78E-25	8.30E-26	10.57
8.00E+00	0.024	0.057	12.165	40.411	17.550	3.06E+23	5.19E+08	8.42E-25	7.93E-26	10.61
9.00E+00	0.023	0.055	12.568	41.749	18.131	3.07E+23	5.20E+08	8.15E-25	7.65E-26	10.65
1.00E+01	0.023	0.054	12.898	42.845	18.607	3.08E+23	5.22E+08	7.94E-25	7.43E-26	10.68
1.10E+01	0.022	0.053	13.170	43.749	19.000	3.09E+23	5.23E+08	7.77E-25	7.26E-26	10.71
1.20E+01	0.022	0.052	13.393	44.489	19.321	3.09E+23	5.25E+08	7.64E-25	7.12E-26	10.74
1.30E+01	0.022	0.051	13.577	45.102	19.587	3.10E+23	5.26E+08	7.54E-25	7.00E-26	10.77
1.40E+01	0.021	0.050	13.726	45.598	19.803	3.11E+23	5.27E+08	7.46E-25	6.91E-26	10.79
1.50E+01	0.021	0.050	13.846	45.996	19.976	3.11E+23	5.28E+08	7.39E-25	6.84E-26	10.81
1.60E+01	0.021	0.050	13.943	46.317	20.115	3.12E+23	5.29E+08	7.34E-25	6.78E-26	10.83
1.80E+01	0.021	0.049	14.084	46.786	20.319	3.13E+23	5.31E+08	7.27E-25	6.69E-26	10.87
2.00E+01	0.021	0.049	14.168	47.064	20.440	3.14E+23	5.33E+08	7.23E-25	6.63E-26	10.90
2.20E+01	0.021	0.049	14.211	47.209	20.503	3.15E+23	5.34E+08	7.20E-25	6.59E-26	10.93
2.40E+01	0.021	0.049	14.226	47.258	20.524	3.16E+23	5.36E+08	7.20E-25	6.57E-26	10.96
2.60E+01	0.021	0.049	14.222	47.245	20.518	3.16E+23	5.37E+08	7.20E-25	6.56E-26	10.98
2.80E+01	0.021	0.049	14.201	47.176	20.488	3.17E+23	5.38E+08	7.21E-25	6.55E-26	11.00
3.00E+01	0.021	0.049	14.171	47.074	20.444	3.17E+23	5.38E+08	7.22E-25	6.56E-26	11.02

Energy	MAC	LAC	HVL	TVL	MFP	Neff	Ceff	ACS	ECS	Zeff
MeV	cm²/g	1/cm	cm	cm	cm	electrons/g	S/m	cm²/g	cm²/g	
4.00E+01	0.021	0.050	13.934	46.289	20.103	3.19E+23	5.42E+08	7.35E-25	6.63E-26	11.08
5.00E+01	0.022	0.051	13.659	45.374	19.706	3.21E+23	5.44E+08	7.50E-25	6.74E-26	11.13
6.00E+01	0.022	0.052	13.405	44.529	19.339	3.21E+23	5.45E+08	7.64E-25	6.85E-26	11.15
8.00E+01	0.023	0.053	12.968	43.080	18.710	3.22E+23	5.47E+08	7.89E-25	7.06E-26	11.19
1.00E+02	0.023	0.055	12.633	41.967	18.226	3.23E+23	5.48E+08	8.10E-25	7.23E-26	11.21
1.50E+02	0.024	0.057	12.059	40.058	17.397	3.23E+23	5.49E+08	8.49E-25	7.56E-26	11.23
2.00E+02	0.025	0.059	11.705	38.883	16.887	3.24E+23	5.49E+08	8.75E-25	7.78E-26	11.24
3.00E+02	0.026	0.061	11.283	37.480	16.277	3.24E+23	5.50E+08	9.07E-25	8.07E-26	11.24
4.00E+02	0.027	0.063	11.038	36.667	15.924	3.24E+23	5.50E+08	9.28E-25	8.25E-26	11.25
5.00E+02	0.027	0.064	10.877	36.132	15.692	3.24E+23	5.50E+08	9.41E-25	8.37E-26	11.25
6.00E+02	0.027	0.064	10.762	35.751	15.527	3.24E+23	5.50E+08	9.51E-25	8.46E-26	11.25
8.00E+02	0.028	0.065	10.607	35.236	15.303	3.24E+23	5.50E+08	9.65E-25	8.58E-26	11.25
1.00E+03	0.028	0.066	10.508	34.905	15.159	3.24E+23	5.50E+08	9.74E-25	8.66E-26	11.25
1.50E+03	0.028	0.067	10.364	34.428	14.952	3.24E+23	5.50E+08	9.88E-25	8.78E-26	11.25
2.00E+03	0.029	0.067	10.287	34.172	14.841	3.24E+23	5.50E+08	9.95E-25	8.85E-26	11.25
3.00E+03	0.029	0.068	10.201	33.888	14.717	3.24E+23	5.50E+08	1.00E-24	8.92E-26	11.25
4.00E+03	0.029	0.068	10.153	33.729	14.648	3.24E+23	5.50E+08	1.01E-24	8.96E-26	11.25
5.00E+03	0.029	0.068	10.126	33.638	14.609	3.24E+23	5.50E+08	1.01E-24	8.99E-26	11.25
6.00E+03	0.029	0.069	10.103	33.563	14.576	3.24E+23	5.50E+08	1.01E-24	9.01E-26	11.25
8.00E+03	0.029	0.069	10.078	33.480	14.540	3.24E+23	5.50E+08	1.02E-24	9.03E-26	11.25
1.00E+04	0.029	0.069	10.060	33.419	14.514	3.24E+23	5.50E+08	1.02E-24	9.05E-26	11.25
1.50E+04	0.029	0.069	10.039	33.348	14.483	3.24E+23	5.50E+08	1.02E-24	9.07E-26	11.25
2.00E+04	0.029	0.069	10.025	33.304	14.464	3.24E+23	5.50E+08	1.02E-24	9.08E-26	11.25
3.00E+04	0.029	0.069	10.011	33.255	14.442	3.24E+23	5.50E+08	1.02E-24	9.09E-26	11.25
4.00E+04	0.029	0.069	10.004	33.231	14.432	3.24E+23	5.50E+08	1.02E-24	9.10E-26	11.25
5.00E+04	0.029	0.069	10.001	33.222	14.428	3.24E+23	5.50E+08	1.02E-24	9.10E-26	11.25
6.00E+04	0.030	0.069	9.997	33.208	14.422	3.24E+23	5.50E+08	1.02E-24	9.11E-26	11.25
8.00E+04	0.030	0.069	9.994	33.200	14.418	3.24E+23	5.50E+08	1.02E-24	9.11E-26	11.25
1.00E+05	0.030	0.069	9.990	33.187	14.413	3.24E+23	5.50E+08	1.02E-24	9.11E-26	11.25

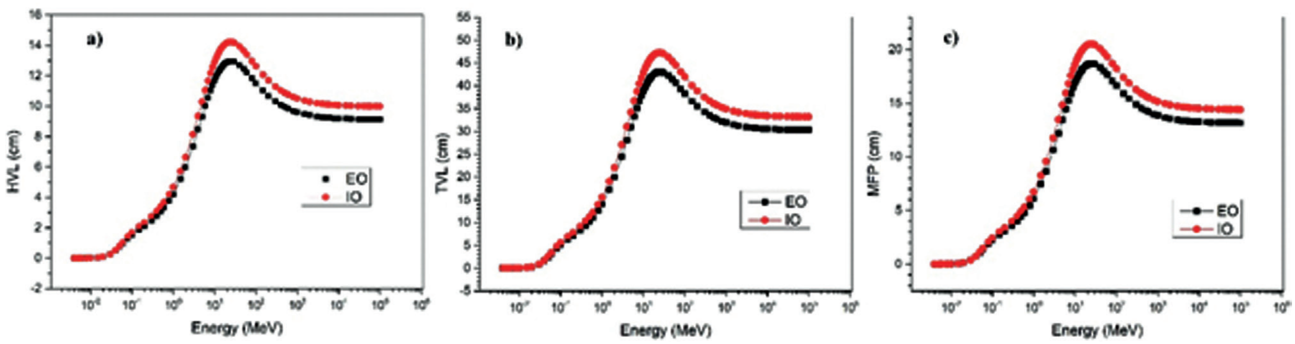

Figure 3. Dependence of HVL (a) TVL (b) and MFP (c) versus incident photon energy.

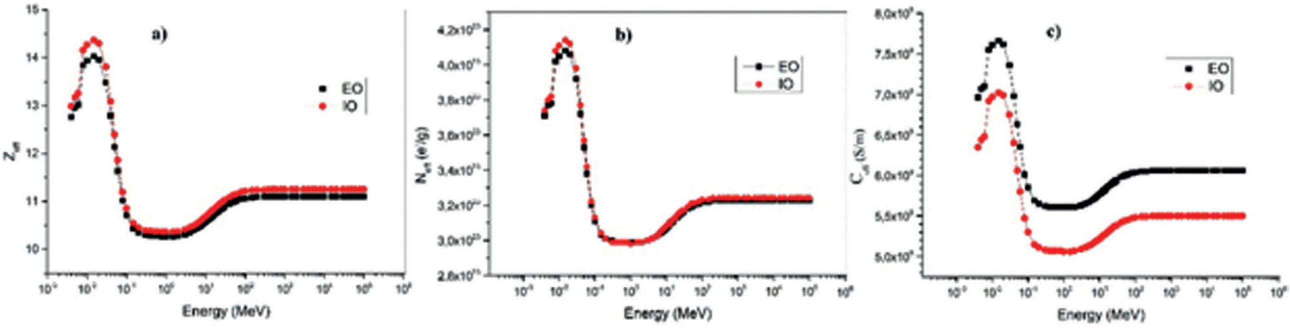

Figure 4. The changes of Z_{eff} (a) N_{eff} (b) and C_{eff} (c) as a function of incident photon energy.

Table 4. MAC and LAC values of EO, IO and OC between the energies of 10keV-1GeV

Energy	EO MAC	EO LAC	IO MAC	IO LAC	OC MAC	OC LAC
MeV	cm²/g	1/cm	cm²/g	1/cm	cm²/g	1/cm
1.00E-02	23.56	61.27	24.86	58.44	22.56	51.89
1.50E-02	7.327	19.05	7.750	18.21	7.079	16.28
2.00E-02	3.226	8.387	3.412	8.019	3.105	7.142
3.00E-02	1.084	2.818	1.141	2.681	1.048	2.410
4.00E-02	0.556	1.445	0.580	1.363	0.541	1.245
5.00E-02	0.365	0.948	0.377	0.887	0.358	0.824
6.00E-02	0.278	0.723	0.285	0.670	0.241	0.555
8.00E-02	0.204	0.531	0.207	0.487	0.204	0.469
1.00E-01	0.173	0.451	0.175	0.411	0.172	0.396
1.50E-01	0.141	0.367	0.142	0.333	0.142	0.328
2.00E-01	0.125	0.326	0.126	0.295	0.127	0.292
3.00E-01	0.107	0.278	0.107	0.252	0.108	0.249
4.00E-01	0.095	0.248	0.095	0.224	0.096	0.222
5.00E-01	0.087	0.226	0.087	0.204	0.088	0.202
6.00E-01	0.080	0.209	0.080	0.188	0.079	0.183
8.00E-01	0.070	0.183	0.070	0.165	0.071	0.164
1.00E+00	0.063	0.164	0.063	0.149	0.064	0.147
1.50E+00	0.051	0.134	0.051	0.121	0.052	0.120
2.00E+00	0.044	0.115	0.044	0.104	0.045	0.103
3.00E+00	0.036	0.094	0.036	0.085	0.036	0.084
4.00E+00	0.032	0.082	0.032	0.074	0.031	0.073
5.00E+00	0.029	0.074	0.029	0.067	0.028	0.066
6.00E+00	0.027	0.069	0.027	0.063	0.026	0.061
8.00E+00	0.024	0.063	0.024	0.057	0.024	0.056
1.00E+01	0.023	0.059	0.023	0.054	0.022	0.052
1.50E+01	0.021	0.055	0,021	0,050	0.021	0.048
2.00E+01	0.021	0.054	0,021	0,049	0.019	0.043
5.00E+01	0.021	0.056	0,022	0,051	0.021	0.048
1.00E+02	0.023	0.060	0,023	0,055	0.022	0.052
5.00E+02	0.027	0.070	0,027	0,064	0.026	0.061
1.00E+03	0.028	0.072	0,028	0,066	0.027	0.063

materials are required and longer MFP would be. It is preferred to have low HVL, TVL and MFP values in the high energy regions for better shielding property. Although, HVL, TVL and MFP values of the obsidians are very close to each other, lower HVL, TVL and MFP values were obtained for EO at high energies.

The energy dependence of Z_{eff}, N_{eff} and C_{eff} are given in Fig. 4(a-c). In the low energy region due to the photoelectric effect, maximum Z_{eff} values were obtained. By increasing energy, these values decreased sharply. Then the values gradually increased and remained constant in high energies. Due to the higher Z_{eff} values of IO than those of EO, it can be said that IO shows higher shielding potential. N_{eff} is one of the most important parameter that represents the effective conductivity of the compound depending on the excitatory photon energy [20]. As shown in Fig. 4, the variation of the N_{eff} values on the incident photon energies is similar with the variation of Z_{eff} values. The interactions between photons and material with photoelectric effect, Compton scattering, and pair production interaction processes cause changes in the number of free electrons in the material. Changing of C_{eff} values versus photon energies showed that EO has higher C_{eff} values than those of IO.

CONCLUSION

In the present study, radiation-matter interaction parameters of IO and EO were obtained to determine the radiation shielding capabilities. For this purpose, the MAC, LAC, HVL, TVL, MFP, ACS, ECS, Z_{eff}, N_{eff} and C_{eff} parameters of the present samples were calculated by Phy-X / PSD code in the range of 4keV-100GeV. According to the obtained results, although, the parameters of the studied obsidians have near values to each other, it was concluded that IO has higher shielding potential compared to EO. It was also obtained that both IO and EO have more shielding ability than that of OC.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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