



Performance of Seven Naturally Occurring Pt-Metallic Materials in Comparison to Their Basic Elements as Photon or Neutron Shielding Materials: MATXCOM vs. NGCal Models

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Abstract

In general, the humans are seeking for safety and protection from the harmful radiations which are fundamental characteristics of their behaviors. Radiation has useful applications but it is important to protect from ionizing radiation. This protection is limited by the shielding material, distance, time, and radiation dose. In the case of neutron, these parameters varied in their effects in comparison to radiation nature. The current study explores the attenuation nature of seven naturally occurred platinum materials against neutron and photon exposure via two models at (0.015-15) MeV. These materials are Isoferroplatinum (Pt_3Fe), Tetra-ferroplatinum ($PtFe$), Tulameenite (Pt_2CuFe), Geversite ($PtSb_2$), Sperryllite ($PtAs_2$), Braggite ($PdPt_3S_4$), and Cooperite (PtS). The web based MATXCOM and NGCal were applied to calculate LAC, MAC, and TVL factors of these materials then compared with Pt, Fe, Cu, Sb, As, Pd, and S. Furthermore, this first Iraqi attempt calculates the protection efficiency (P%) of all the tested materials and their basic elements and defines the best shielding materials against neutron or photon exposure. Between all the tested naturally occurred materials, the Pt_3Fe was found to be the superior photon or thermal neutron shielding protector due to its higher LAC and MAC and lower TVL at the applied photon energy whereas Pt_2CuFe was superior fast neutron shielding material. This conclusion is based on the obtained P% data in addition to the LAC, MAC, and TVL. Moreover, density, mean atomic number, and crystal system are essential factors that influence the interactions between each material and the incident photons or the neutrons.

1. Introduction

In general, the humans are seeking for safety and protection from harmful things or situations which are fundamental characteristics of their behaviors. Radiation is a past and present-day example that has useful applications such as power plants, industry, agriculture, space, medicine, and others fields. From the other side, it is an important issue to protect from ionizing radiation. This protection is limited by shielding material, distance, time, and radiation dose. In the case of neutron, these parameters varied in their effects in comparison to radiation nature [1].

Now days, many materials have been used or studied as protection materials such as iron, nickel, tellurium, lead, platinum and rhodium-based Alloys, polymer, composites, glasses, and other materials [2-16]. Akman et al. (2025) explored the shielding characteristics of platinum and rhodium-based alloys where the interactions of charged (p or α) particles with matter and gamma radiation attenuation properties: mass stopping power, projected range, MAC, LAC, HVL, TVL, MFP, ... etc. were theoretically determined in the energy range (0.06-2.614) MeV via Geant4 and MCNP6. The obtained nuclear data show that the Pt- and Rh - alloys exhibit great performance in this issue and Pt₉₄Rh₆ being the superior candidate protective among other tested alloys (Pt₉₀Rh₁₀, Pt₈₇Rh₁₃, Pt₈₃Rh₁₇, and Pt₇₀Rh₃₀, Pt₆₀Rh₄₀) [10].

To describe how gamma rays or neutrons attenuate via losing energy in the tested material, there are experimental tests or theoretical models governed by the Lambert- Beer Law. The exponential formula of the Lambert- Beer Law is:

$$I/I_0 = e^{-\mu x} \quad (1)$$

Where: I and I₀ are the penetrated and incident intensities, respectively, x is thickness, and linear attenuation coefficient (LAC, μ).

Both experimental and theoretical data define the exponentially energy behavior with absorber thickness via considering photon conversion to electron-positron pair at high energy (pair production), losing intermediate energy via scattering step (Compton scattering), and energy absorption that causes electron ejection (photoelectric effect) as the matter-rays interactions [17, 18] (Figure 1).

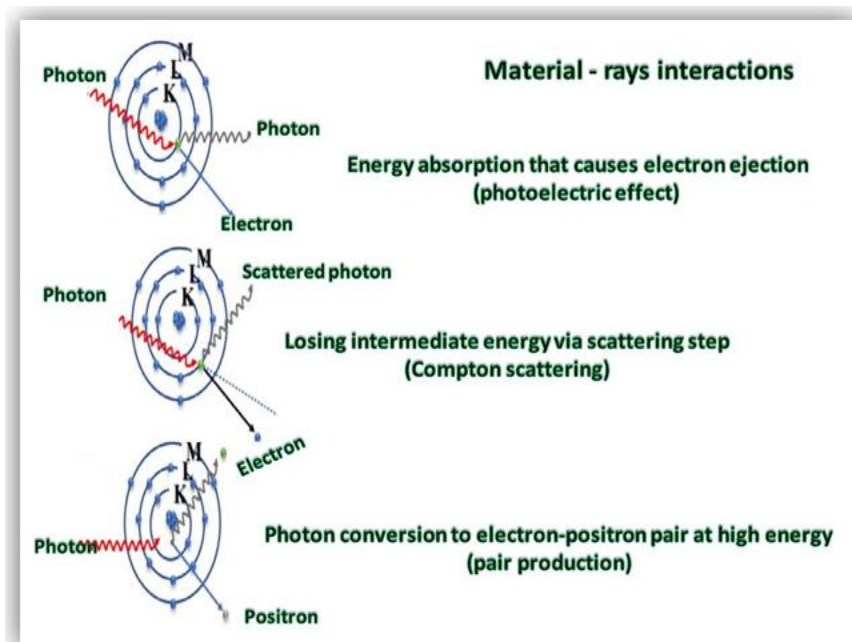


Figure (1): Photon interactions with materials known as photoelectric effect, Compton scattering, and pair production.

The interaction between the incident neutron and the atomic nucleus leads to several penetration action such as elastic or inelastic scattering in addition to neutron capture. These interactions can induce nuclear fission or transmutation reactions which produce new atomic characteristics. Furthermore, these interactions can be moderated or shielded via specialized materials. In elastic scattering, the collisions between the neutron and nucleus result slowing down the neutron (moderation) whereas inelastic scattering nucleus transfers to the excited state after energy absorption, releasing gamma rays, and low energy-scattered neutron. In neutron capture, each neutron can create unstable isotope after its absorption by the nucleus and gamma rays emitting [19] (Figure 2).

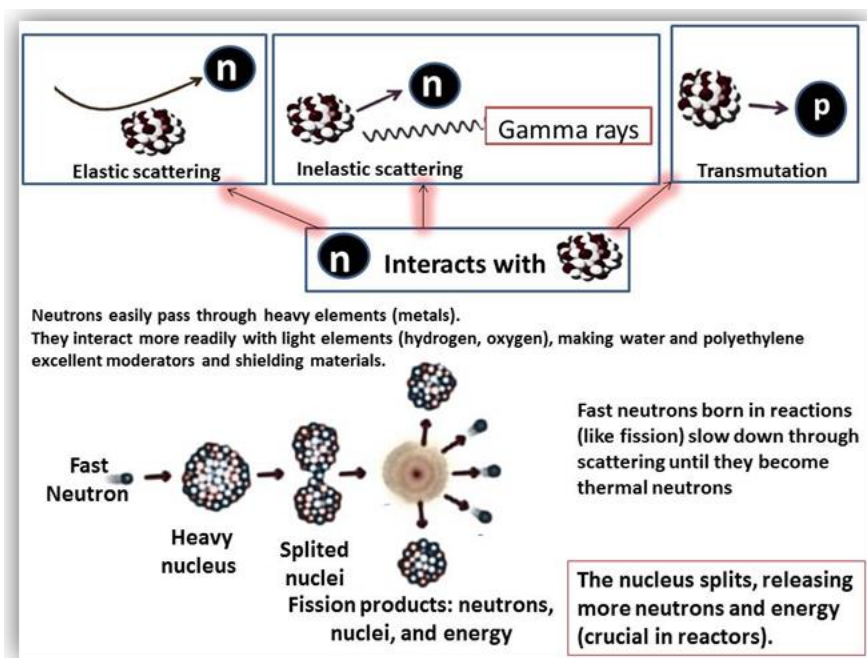


Figure (2): Neutron interactions with nuclei.

Various theoretical models were applied in these radiological calculations depending at the semi-empirical formulas, Monte Carol simulations, or tabulated data such as XCOM, Geant4, MCNP, Phy-X/PSD, NGCal, MATXCOM, and others [2-16, 20-26]. The MATXCOM is a stand- alone theoretical X-rays and gamma rays calculator written via Fortran language for easily computation of Mass and Linear Attenuation Coefficients (MAC and LAC), Tenth Value Level (TVL), and other attenuation factors based on the EPICS2023/EPDL data source [20]. The other free computational software is NGCal used to assess the shielding properties of fast and thermal neutrons in addition to photon interactions (incoherent scattering and absorption of X-rays or gamma rays). This simulation platform performs the shielding effectiveness of element/oxide/ compound via weight fraction or empirical formula [26]. Both practical software packages are friendly designed as web-based tool and they provide more realistic results in comparison to XCOM, Phy-X/PSD, or other models where their accurate and dependable results may be used in dosimetrical, engineering, medical, shielding, and other applications [20, 26].

In the present paper, radiation shielding characteristics of seven naturally platinum-group minerals known as isoferroplatinum, tetraferroplatinum, Tulameenite, geversite, sperrylite, braggite, and cooperite varied in their chemical and physical properties in addition to their basic elements: platinum (Pt), Iron (Fe), Antimony (Sb), Copper (Cu), Arsenic (As), Palladium (Pd), and Sulfur (S) were investigated. To explore the attenuation properties of each material, Mass and Linear Attenuation Coefficients (MAC and LAC), and Tenth Value Level (TVL) were determined at the photon energy range of 0.015MeV to 15 MeV via two mathematical models (MATXCOM and NGCal). In addition, thermal and fast neutrons were studied via NGCal model. The other calculated character was protection performance of each material at various hypothetical thicknesses. The obtained shielding data are important for all the mentioned applications and confirms which naturally occurring Platinum - metallic alloy is superior protector against gamma radiation or neutron exposure.

2. Experimental Procedure

The tested materials are platinum (Pt), Iron (Fe), Antimony (Sb), Copper (Cu), Arsenic (As), Palladium (Pd), and Sulfur (S) in addition to seven naturally platinum-group minerals known as isoferroplatinum, tetraferroplatinum, Tulameenite, geversite, sperrylite, braggite, and cooperite (Table 1, Figure 3). Table (1) shows the chemical formula, crystal system, density, mean atomic number of each material whereas Figure (3) shows the naturally occurring Pt materials and their basic elements from Mindat.org of the Hudson Institute of Mineralogy [27]. Each tested material was subjected to two mathematical models (MATXCOM [20] and NGCal [26] to investigate the Mass and Linear Attenuation Coefficients (MAC and LAC), and Tenth Value Level (TVL) at the energy range of

0.015MeV to 15 MeV (Figure 4, Tables 2-8). In addition, the LAC (μ) and MAC (μ_m) of the thermal and fast neutrons were studied via NGCal model at energy of 25.4 meV and 4 MeV respectively. By simple calculations, the fast neutron has the energy of 4 MeV and it is approximately 157 million times larger than thermal neutron with 25.4 meV (or 2.54×10^{-8} MeV). Equation (2) shows the relationship between LAC, MAC, and the density of the tested material (ρ , gm/cm³) whereas Equation (3) shows its relationship with TVL. From Equation (1), LAC (μ , cm⁻¹) represent the fundamental factor in attenuation subject according to the exponential formula of the Lambert-Beer Law that is the basis of other shielding parameters such as MAC (μ_m , cm²/g) and TVL (Equations 2 and 3, Tables 2-8). The TVL characterizes the thickness (cm) that reduces the radiation intensity by one tenth (Tables 5 and 8). In addition, the LAC and the TVL have an inverse relationship whereas the MAC and the LAC have a proportional relationship (Tables 2-8). Moreover, Equation (2) shows the MAC dependence on the density (ρ , gm/cm³) of each material and it shapes the interaction probability between each material and the incident photons or neutrons. The other calculated character in this paper is the percentage of difference ($\Delta\%$) between the NGCal and MATXCOM was calculated depending on their LAC data ((μ_{NGCal}) and (μ_{MATXCOM})) respectively (Equation 4, Table 9) [28-30].

$$\text{MAC} = \mu_m = \mu/\rho \quad (2)$$

$$\text{TVL} = \ln 10/\mu \quad (3)$$

$$\Delta\% = (\mu_{\text{NGCal}} - \mu_{\text{MATXCOM}})/\mu_{\text{NGCal}} \times 100 \quad (4)$$

Furthermore, the Protection Efficiency (P%) was calculated depending on the Beer–Lamberts law (Equation 1) [30, 31] and LAC data. This formula (Equation 1) is mathematical modifies to Equation (5) and the shielding thickness was hypothesized as $x = (0.5, 1, 5, \text{ and } 10)$ cm (Tables 10-14).

$$\text{Protection Efficiency (P\%)} = (1 - (e^{-\mu x})) \times 100 \quad (5)$$

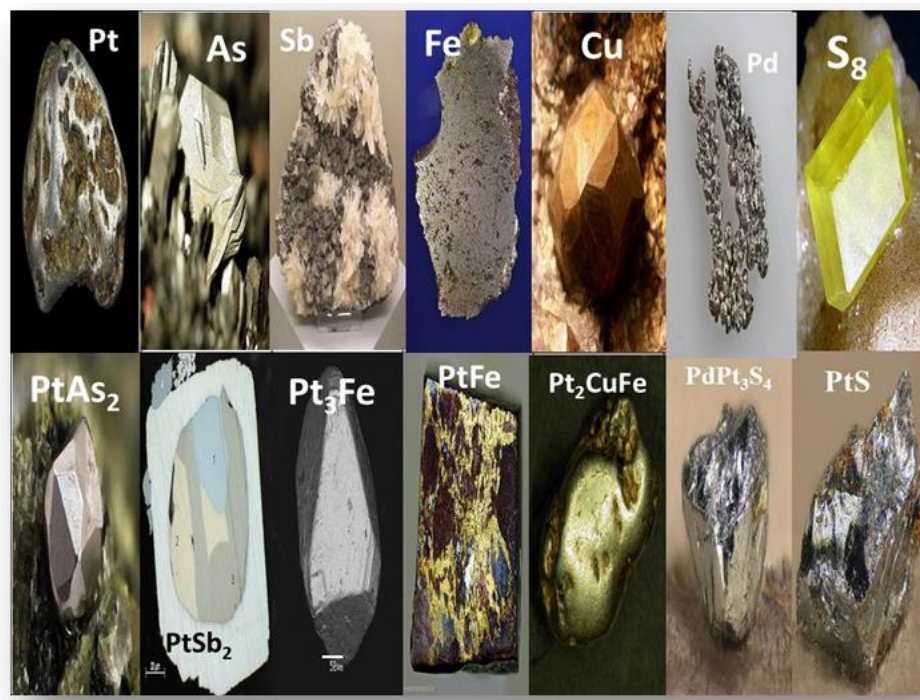


Figure (3): Platinum (Pt), Iron (Fe), Antimony (Sb), Copper (Cu), Arsenic (As), Palladium (Pd), Sulfur (S), and the seven Pt materials from Mindat.org of the Hudson Institute of Mineralogy [27].

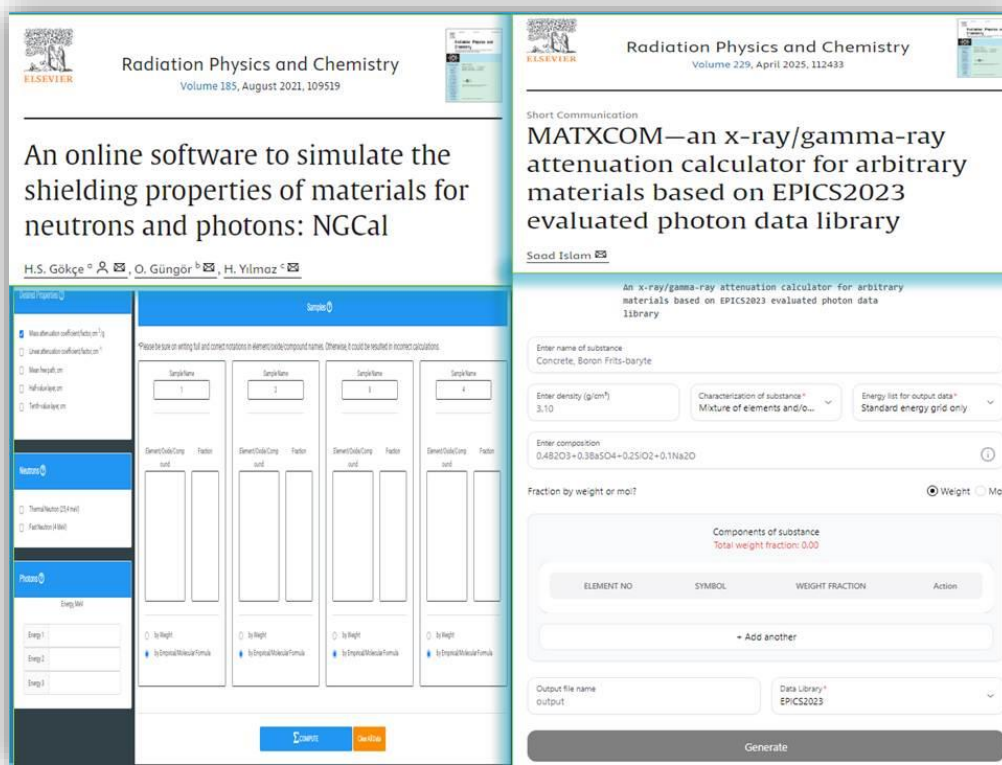


Figure (4): NGCal and MATXCOM platforms [20, 26].

Table (1): The chemical formula, elemental fraction, crystal system, density, and mean atomic number of each material.

Name	Formula	Elemental fraction	Crystal System	Density. gm/cm3	Mean Atomic number			
Platinum	Pt	Pt	1	Isometric	21.452	78		
	Iron	Fe	Fe	1	Primordial	7.874	26	
		Copper	Cu	Cu	1	Primordial	8.935	29
			Antimony	Sb	Sb	1	Rhombohedral	6.694
Arsenic	As	As	1	Primordial	5.782	33		
Palladium	Pd	Pd	1	Primordial	12.007	46		
Sulfur (α - phase)	S	S	1	Primordial	2.07	16		
Isoferroplatinum	Pt ₃ Fe	Pt	0.9129	Isometric	18.41	65		
		Fe	0.0871					
Tetraferroplatinum	PtFe	Pt	0.7774	Tetragonal	15.7	52		
		Fe	0.2226					
Tulameenite	Pt ₂ CuFe	Pt	0.7657	Tetragonal	14.9	52.75		
		Cu	0.1247					
		Fe	0.1096					
Geversite	PtSb ₂	Pt	0.4448	Isometric	10.97	60		
		Sb	0.5552					
Sperrylite	PtAs ₂	Pt	0.5656	Isometric	10.58	48		
		As	0.4344					

Name	Formula	Elemental fraction		Crystal System	Density. gm/cm ³	Mean Atomic number
Braggite	PdPt ₃ S ₄	Pd	0.1298	Tetragonal	9.63	43
		Pt	0.7138			
		S	0.1564			
		Pt	0.8588			

Table (2): The Mass and Linear Attenuation Coefficients (MAC and LAC) calculated by NGCal software of the tested materials with their basic elements exposed to the thermal and fast neutrons.

ID	Mass attenuation factor. cm ² /g		Linear attenuation factor. cm ⁻¹		ID	Mass attenuation factor. cm ² /g		Linear attenuation factor. cm ⁻¹	
	Thermal (25.4 meV)	Fast (4 MeV)	Thermal (25.4 meV)	Thermal (25.4 meV)		Thermal (25.4 meV)	Fast (4 MeV)	Thermal (25.4 meV)	Thermal (25.4 meV)
Pt	0.03220	0.00040	0.69064	0.00867	Pt ₃ Fe	0.03217	0.00074	0.59231	0.01371
Fe	0.031919	0.004313	0.2513	0.0340	PtFe	0.03214	0.00127	0.50453	0.02001
Cu	0.041035	0.005212	0.3677	0.0467	Pt ₂ CuFe	0.03327	0.00143	0.49571	0.02134
Sb	0.02432	3.46E-05	0.1628	0.0002	PtSb ₂	0.02782	0.00020	0.30522	0.00218
As	0.036653	0.000482	0.2119	0.0028	PtAs ₂	0.03413	0.00044	0.36113	0.00464
Pd	0.0396	0.0005	0.4751	0.0064	PdPt ₃ S ₄	0.02970	0.00038	0.28656	0.00365
S	0.0101	0.0001	0.0209	0.0003	PtS	0.02908	0.00037	0.27622	0.00348

Table (3a): The Linear Attenuation Coefficient (LAC. cm⁻¹) calculated by MATXCOM software of the basic elements related to the tested materials which exposed to the photons (the yellow highlight is to distinguish the little rise of the LAC).

E. MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	3380.432	449.77091	663.94014	329.46539	568.25058	445.05600	32.13702
0.02	1625.071	202.55967	303.13867	151.25094	264.32829	202.92068	13.90446
0.03	566.795	64.51818	97.96634	49.33149	87.28791	415.36926	4.37841
0.04	266.644	28.68549	43.69680	135.65331	39.18236	194.17419	2.04770
0.05	148.351	15.46530	23.48140	75.11562	21.07422	106.48791	1.21384
0.06	92.005	9.52295	14.31944	46.15983	12.77701	65.01618	0.84105
0.08	186.836	4.70509	6.85723	21.31728	5.97457	29.86104	0.53637
0.1	107.078	2.93691	4.11927	11.80064	3.46509	16.57499	0.41876
0.15	38.560	1.54982	1.99062	4.27171	1.52098	6.16133	0.31179
0.2	19.121	1.15104	1.39942	2.26767	0.99542	3.39904	0.26947
0.3	7.781	0.86529	1.00278	1.12223	0.66480	1.80900	0.22582
0.4	4.543	0.73991	0.84298	0.78349	0.54403	1.32291	0.19995
0.5	3.195	0.66236	0.74898	0.63186	0.47713	1.09591	0.18165
0.6	2.509	0.60643	0.68305	0.54498	0.43233	0.96084	0.16752
0.8	1.810	0.52698	0.59102	0.44556	0.37193	0.79940	0.14676

E. MeV	Pt	Fe	Cu	Sb	As	Pd	S
1	1.466	0.47142	0.52797	0.38723	0.33115	0.70081	0.13174
1.5	1.093	0.38399	0.42970	0.30921	0.26913	0.56340	0.10735
2.0	0.968	0.33524	0.37603	0.27422	0.23624	0.49855	0.09291
3.0	0.890	0.28471	0.32188	0.24636	0.20427	0.44385	0.07674
4.0	0.883	0.26022	0.29668	0.23834	0.19027	0.42561	0.06801
5.0	0.899	0.24722	0.28404	0.23783	0.18392	0.42163	0.06271
6.0	0.923	0.24025	0.27794	0.24050	0.18129	0.42388	0.05930
8.0	0.982	0.23512	0.27495	0.25034	0.18165	0.43774	0.05540
10.0	1.044	0.23540	0.27761	0.26216	0.18516	0.45587	0.05349
15.0	1.187	0.24316	0.29054	0.29101	0.19668	0.50150	0.05199

Table (3b): The Linear Attenuation Coefficient (LAC. cm^{-1}) calculated by MATXCOM software of the tested materials which exposed to the photons (the yellow highlight is to distinguish the little rise of the LAC).

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	2739.961	2123.001	2028.785	1068.647	1394.643	1152.871	1306.507
0.02	1314.396	1014.526	969.137	507.239	663.413	551.946	627.075
0.03	457.189	351.128	335.136	173.802	227.487	228.037	218.407
0.04	214.741	164.446	156.820	184.077	105.524	107.141	102.740
0.05	119.373	91.272	86.975	102.089	58.133	59.503	57.209
0.06	74.019	56.575	53.875	62.927	35.820	36.860	35.537
0.08	147.333	108.395	101.763	61.892	56.865	63.365	71.407
0.1	84.487	62.229	58.411	35.092	32.623	36.340	40.997
0.15	30.525	22.628	21.242	12.657	11.965	13.224	14.868
0.2	15.215	11.390	10.698	6.412	6.125	6.677	7.447
0.3	6.272	4.811	4.526	2.791	2.699	2.846	3.106
0.4	3.710	2.913	2.744	1.746	1.700	1.739	1.857
0.5	2.638	2.112	1.992	1.302	1.271	1.270	1.333
0.6	2.089	1.697	1.602	1.067	1.043	1.026	1.063
0.8	1.525	1.264	1.194	0.817	0.800	0.770	0.783
1	1.245	1.044	0.987	0.686	0.672	0.639	0.643
1.5	0.935	0.793	0.750	0.530	0.519	0.487	0.485
2.0	0.826	0.699	0.662	0.470	0.458	0.430	0.428
3.0	0.756	0.633	0.599	0.427	0.411	0.387	0.388
4.0	0.745	0.618	0.585	0.418	0.398	0.377	0.380
5.0	0.754	0.621	0.588	0.421	0.397	0.378	0.382
6.0	0.772	0.632	0.599	0.429	0.402	0.383	0.390
8.0	0.818	0.663	0.628	0.451	0.418	0.401	0.410
10.0	0.866	0.699	0.662	0.476	0.438	0.421	0.432
15.0	0.979	0.783	0.742	0.535	0.487	0.470	0.485

Table (4a): The Mass Attenuation Coefficient (MAC, cm²/gm) calculated by MATXCOM software of the basic elements related to the tested materials which exposed to the photons (the yellow highlight is to distinguish the little rise of the MAC).

E. MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	157.58121	57.12102	74.10046	49.21801	98.27924	37.06638	15.52513
0.02	75.75380	25.72513	33.83244	22.59500	45.71572	16.90020	6.71713
0.03	26.42155	8.19382	10.93374	7.36951	15.09649	34.59393	2.11517
0.04	12.42980	3.64306	4.87688	20.26491	6.77661	16.17175	0.98923
0.05	6.91548	1.96410	2.62069	11.22134	3.64480	8.86882	0.58640
0.06	4.28886	1.20942	1.59815	6.89570	2.20979	5.41486	0.40630
0.08	8.70949	0.59755	0.76532	3.18454	1.03331	2.48697	0.25912
0.1	4.99153	0.37299	0.45974	1.76287	0.59929	1.38044	0.20230
0.15	1.79750	0.19683	0.22217	0.63814	0.26305	0.51314	0.15062
0.2	0.89134	0.14618	0.15619	0.33876	0.17216	0.28309	0.13018
0.3	0.36273	0.10989	0.11192	0.16765	0.11498	0.15066	0.10909
0.4	0.21177	0.09397	0.09408	0.11704	0.09409	0.11018	0.09659
0.5	0.14895	0.08412	0.08359	0.09439	0.08252	0.09127	0.08775
0.6	0.11695	0.07702	0.07623	0.08141	0.07477	0.08002	0.08093
0.8	0.08436	0.06693	0.06596	0.06656	0.06433	0.06658	0.07090
1	0.06835	0.05987	0.05892	0.05785	0.05727	0.05837	0.06364
1.5	0.05097	0.04877	0.04796	0.04619	0.04655	0.04692	0.05186
2.0	0.04510	0.04258	0.04197	0.04096	0.04086	0.04152	0.04489
3.0	0.04151	0.03616	0.03592	0.03680	0.03533	0.03697	0.03707
4.0	0.04117	0.03305	0.03311	0.03560	0.03291	0.03545	0.03285
5.0	0.04190	0.03140	0.03170	0.03553	0.03181	0.03512	0.03030
6.0	0.04304	0.03051	0.03102	0.03593	0.03135	0.03530	0.02865
8.0	0.04580	0.02986	0.03069	0.03740	0.03142	0.03646	0.02676
10.0	0.04867	0.02990	0.03098	0.03916	0.03202	0.03797	0.02584
15.0	0.05533	0.03088	0.03243	0.04347	0.03402	0.04177	0.02512

Table (4b): The Mass Attenuation Coefficient (MAC, cm²/gm) calculated by MATXCOM software of the tested materials which exposed to the photons (the yellow highlight is to distinguish the little rise of the MAC).

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	148.83003	135.22296	136.16009	97.41540	131.81882	119.71661	137.52710
0.02	71.39575	64.61950	65.04274	46.23878	62.70444	57.31522	66.00787
0.03	24.83372	22.36482	22.49234	15.84341	21.50164	23.67990	22.99021
0.04	11.66438	10.47424	10.52486	16.78004	9.97390	11.12577	10.81473
0.05	6.48416	5.81351	5.83722	9.30619	5.49461	6.17892	6.02200
0.06	4.02061	3.60350	3.61580	5.73624	3.38566	3.82764	3.74076
0.08	8.00285	6.90411	6.82972	5.64191	5.37475	6.57991	7.51655
0.1	4.58921	3.96364	3.92019	3.19890	3.08342	3.77363	4.31544
0.15	1.65806	1.44126	1.42561	1.15380	1.13090	1.37317	1.56501
0.2	0.82643	0.72550	0.71799	0.58454	0.57891	0.69332	0.78389

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.3	0.34070	0.30646	0.30374	0.25441	0.25510	0.29552	0.32692
0.4	0.20151	0.18556	0.18419	0.15918	0.16065	0.18057	0.19551
0.5	0.14331	0.13452	0.13370	0.11866	0.12009	0.13189	0.14031
0.6	0.11347	0.10806	0.10750	0.09722	0.09863	0.10652	0.11187
0.8	0.08284	0.08048	0.08015	0.07448	0.07566	0.07994	0.08246
1	0.06761	0.06647	0.06625	0.06252	0.06354	0.06632	0.06769
1.5	0.05078	0.05048	0.05035	0.04832	0.04905	0.05058	0.05110
2.0	0.04488	0.04454	0.04443	0.04280	0.04326	0.04460	0.04507
3.0	0.04104	0.04032	0.04022	0.03889	0.03882	0.04022	0.04088
4.0	0.04046	0.03936	0.03927	0.03808	0.03758	0.03913	0.04000
5.0	0.04098	0.03956	0.03947	0.03836	0.03751	0.03920	0.04026
6.0	0.04195	0.04025	0.04017	0.03909	0.03796	0.03979	0.04101
8.0	0.04441	0.04225	0.04216	0.04113	0.03955	0.04161	0.04311
10.0	0.04704	0.04449	0.04441	0.04339	0.04144	0.04371	0.04545
15.0	0.05320	0.04989	0.04979	0.04875	0.04607	0.04884	0.05106

Table (5a): The Tenth Value Level (TVL. cm) calculated by MATXCOM software of the basic elements related to the tested materials, which exposed to the photons (the yellow highlight is to distinguish the little decrease of the TVL).

E. MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	0.00068	0.00512	0.00347	0.00699	0.00405	0.00517	0.07165
0.02	0.00142	0.01137	0.00760	0.01522	0.00871	0.01135	0.16560
0.03	0.00406	0.03569	0.02350	0.04668	0.02638	0.00554	0.52590
0.04	0.00864	0.08027	0.05269	0.01697	0.05877	0.01186	1.12448
0.05	0.01552	0.14889	0.09806	0.03065	0.10926	0.02162	1.89694
0.06	0.02503	0.24179	0.16080	0.04988	0.18021	0.03542	2.73776
0.08	0.01232	0.48938	0.33579	0.10801	0.38540	0.07711	4.29288
0.1	0.02150	0.78402	0.55898	0.19512	0.66451	0.13892	5.49854
0.15	0.05971	1.48571	1.15672	0.53903	1.51388	0.37372	7.38513
0.2	0.12042	2.00044	1.64538	1.01540	2.31318	0.67742	8.54499
0.3	0.29592	2.66106	2.29620	2.05179	3.46360	1.27285	10.19677
0.4	0.50685	3.11197	2.73149	2.93887	4.23249	1.74055	11.51572
0.5	0.72060	3.47635	3.07431	3.64415	4.82594	2.10108	12.67620
0.6	0.91778	3.79697	3.37103	4.22506	5.32599	2.39643	13.74531
0.8	1.27240	4.36939	3.89593	5.16783	6.19084	2.88041	15.68957
1	1.57031	4.88436	4.36124	5.94636	6.95331	3.28560	17.47760
1.5	2.10589	5.99654	5.35853	7.44655	8.55560	4.08697	21.45028
2.0	2.37991	6.86839	6.12337	8.39694	9.74675	4.61855	24.78215
3.0	2.58602	8.08760	7.15365	9.34656	11.27228	5.18776	30.00311
4.0	2.60720	8.84851	7.76126	9.66096	12.10168	5.41012	33.85713
5.0	2.56195	9.31389	8.10642	9.68181	12.51942	5.46111	36.71694
6.0	2.49375	9.58415	8.28459	9.57414	12.70105	5.43219	38.83021
8.0	2.34385	9.79304	8.37446	9.19771	12.67567	5.26019	41.56104
10.0	2.20531	9.78156	8.29435	8.78319	12.43594	5.05094	43.05050
15.0	1.93997	9.46939	7.92523	7.91234	11.70724	4.59143	44.28686

Table (5b): The Tenth Value Level (TVL. cm) calculated by MATXCOM software of the tested materials, which exposed to the photons (the yellow highlight is to distinguish the little decrease of the TVL).

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	0.00084	0.00108	0.00113	0.00215	0.00165	0.00200	0.00176
0.02	0.00175	0.00227	0.00238	0.00454	0.00347	0.00417	0.00367
0.03	0.00504	0.00656	0.00687	0.01325	0.01012	0.01010	0.01054
0.04	0.01072	0.01400	0.01468	0.01251	0.02182	0.02149	0.02241
0.05	0.01929	0.02523	0.02647	0.02255	0.03961	0.03870	0.04025
0.06	0.03111	0.04070	0.04274	0.03659	0.06428	0.06247	0.06479
0.08	0.01563	0.02124	0.02263	0.03720	0.04049	0.03634	0.03225
0.1	0.02725	0.03700	0.03942	0.06562	0.07058	0.06336	0.05617
0.15	0.07543	0.10176	0.10840	0.18192	0.19245	0.17413	0.15487
0.2	0.15134	0.20215	0.21523	0.35909	0.37594	0.34487	0.30920
0.3	0.36710	0.47857	0.50878	0.82503	0.85315	0.80909	0.74139
0.4	0.62067	0.79039	0.83902	1.31864	1.35473	1.32418	1.23969
0.5	0.87277	1.09022	1.15587	1.76891	1.81223	1.81288	1.72740
0.6	1.10221	1.35716	1.43757	2.15899	2.20663	2.24462	2.16666
0.8	1.50982	1.82237	1.92800	2.81831	2.87666	2.99089	2.93941
1	1.84978	2.20657	2.33269	3.35730	3.42519	3.60528	3.58075
1.5	2.46314	2.90538	3.06907	4.34415	4.43719	4.72697	4.74366
2.0	2.78675	3.29287	3.47791	4.90366	5.03113	5.36078	5.37772
3.0	3.04754	3.63779	3.84188	5.39657	5.60590	5.94436	5.92887
4.0	3.09112	3.72597	3.93478	5.51206	5.79125	6.11119	6.06011
5.0	3.05190	3.70734	3.91485	5.47171	5.80141	6.09939	6.02049
6.0	2.98141	3.64345	3.84709	5.36933	5.73257	6.00983	5.91019
8.0	2.81650	3.47138	3.66507	5.10293	5.50295	5.74690	5.62249
10.0	2.65907	3.29627	3.47990	4.83722	5.25195	5.47020	5.33302
15.0	2.35101	2.93981	3.10354	4.30591	4.72401	4.89543	4.74653

Table (6): The Mass Attenuation Coefficient (MAC, cm²/gm) calculated by NGCal software of the tested materials with their basic elements exposed to the photons (the yellow highlight is to distinguish the little rise of the MAC).

ID	0.015 MeV	0.02 MeV	0.03 MeV	0.04 MeV	0.05 MeV	0.06 MeV	0.08 MeV	0.1 MeV	0.15 MeV	0.2 MeV	0.3 MeV	0.4 MeV	0.5 MeV
Pt	157.8	75.74	26.41	12.45	6.954	4.339	8.731	4.993	1.795	0.89	0.363	0.212	0.149
Fe	57.08	25.68	8.176	3.629	1.958	1.205	0.595	0.372	0.196	0.146	0.11	0.094	0.084
Cu	74.05	33.79	10.92	4.862	2.613	1.593	0.763	0.458	0.222	0.156	0.112	0.094	0.084
Sb	49.23	22.68	7.631	20.27	11.2	6.879	3.176	1.758	0.636	0.338	0.168	0.117	0.095
As	98.56	45.64	15.06	6.76	3.635	2.203	1.03	0.597	0.262	0.172	0.115	0.094	0.083
Pd	37.15	17.04	34.65	16.14	8.85	5.399	2.481	1.377	0.512	0.283	0.151	0.11	0.091
S	15.5	6.708	2.113	0.987	0.585	0.405	0.259	0.202	0.151	0.13	0.109	0.097	0.088
Pt ₃ Fe	149.026	71.379	24.822	11.682	6.519	4.066	8.022	4.59	1.656	0.825	0.341	0.202	0.144
PtFe	135.384	64.599	22.352	10.487	5.842	3.642	6.92	3.965	1.439	0.724	0.306	0.186	0.135

Pt ₂ CuFe	136.317	65.022	22.48	10.537	5.865	3.653	6.846	3.921	1.424	0.717	0.304	0.184	0.134
PtSb ₂	97.52	46.28	15.984	16.792	9.311	5.749	5.647	3.197	1.152	0.583	0.254	0.159	0.119
PtAs ₂	132.065	62.664	21.479	9.978	5.512	3.411	5.386	3.083	1.129	0.578	0.255	0.161	0.12
PdPt ₃ S ₄	119.88	57.322	23.679	11.136	6.204	3.861	6.594	3.774	1.371	0.692	0.295	0.181	0.132
PtS	137.712	65.995	22.98	10.832	6.055	3.784	7.535	4.317	1.563	0.782	0.327	0.196	0.141
ID	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	2 MeV	3 MeV	4 MeV	5 MeV	6 MeV	8 MeV	10 MeV	15 MeV	
Pt	0.117	0.085	0.069	0.051	0.045	0.042	0.041	0.042	0.043	0.046	0.049	0.055	
Fe	0.077	0.067	0.06	0.049	0.043	0.036	0.033	0.031	0.031	0.03	0.03	0.031	
Cu	0.076	0.066	0.059	0.048	0.042	0.036	0.033	0.032	0.031	0.031	0.031	0.032	
Sb	0.082	0.067	0.058	0.046	0.041	0.037	0.036	0.036	0.036	0.037	0.039	0.044	
As	0.075	0.064	0.057	0.047	0.041	0.035	0.033	0.032	0.031	0.031	0.032	0.034	
Pd	0.08	0.067	0.058	0.047	0.042	0.037	0.036	0.035	0.035	0.037	0.038	0.042	
S	0.081	0.071	0.064	0.052	0.045	0.037	0.033	0.03	0.029	0.027	0.026	0.025	
Pt ₃ Fe	0.113	0.083	0.068	0.051	0.045	0.041	0.041	0.041	0.042	0.045	0.047	0.053	
PtFe	0.108	0.081	0.067	0.051	0.045	0.04	0.039	0.04	0.04	0.042	0.045	0.05	
Pt ₂ CuFe	0.107	0.08	0.066	0.051	0.045	0.04	0.039	0.04	0.04	0.042	0.045	0.05	
PtSb ₂	0.097	0.075	0.063	0.048	0.043	0.039	0.038	0.038	0.039	0.041	0.043	0.049	
PtAs ₂	0.099	0.076	0.064	0.049	0.043	0.039	0.038	0.038	0.038	0.04	0.042	0.046	
PdPt ₃ S ₄	0.106	0.08	0.067	0.051	0.045	0.04	0.039	0.039	0.04	0.042	0.044	0.049	
PtS	0.112	0.083	0.068	0.051	0.045	0.041	0.04	0.04	0.041	0.043	0.046	0.051	

Table (7): The Linear Attenuation Coefficient (LAC. cm⁻¹) calculated by NGCal software of the tested materials with their basic elements exposed to the photons (the yellow highlight is to distinguish the little rise of the LAC).

ID	0.015 MeV	0.02 MeV	0.03 MeV	0.04 MeV	0.05 MeV	0.06 MeV	0.08 MeV	0.1 MeV	0.15 MeV	0.2 MeV	0.3 MeV	0.4 MeV	0.5 MeV
Pt	3384.810	1624.623	566.495	267.053	149.163	93.072	187.280	107.100	38.503	19.084	7.776	4.544	3.201
Fe	449.448	202.204	64.378	28.575	15.417	9.488	4.687	2.927	1.547	1.150	0.865	0.740	0.663
Cu	661.637	301.914	97.570	43.442	23.347	14.234	6.817	4.096	1.981	1.393	1.000	0.841	0.747
Sb	329.546	151.820	51.082	135.687	74.973	46.048	21.260	11.768	4.258	2.263	1.123	0.785	0.633
As	569.874	263.891	87.077	39.086	21.018	12.738	5.956	3.452	1.516	0.994	0.665	0.544	0.478
Pd	796.942	365.542	743.312	346.235	189.850	115.819	53.222	29.539	10.973	6.065	3.231	2.366	1.959
S	32.085	13.886	4.374	2.044	1.211	0.839	0.535	0.418	0.312	0.270	0.226	0.200	0.182
Pt ₃ Fe	2743.568	1314.090	456.965	215.058	120.011	74.855	147.690	84.510	30.482	15.185	6.269	3.710	2.642
PtFe	2125.521	1014.197	350.923	164.642	91.721	57.171	108.648	62.242	22.596	11.368	4.809	2.914	2.115
Pt ₂ CuFe	2031.119	968.826	334.949	157.000	87.390	54.431	102.000	58.423	21.212	10.677	4.523	2.745	1.995
PtSb ₂	1069.798	507.695	175.340	184.206	102.147	63.069	61.945	35.070	12.633	6.400	2.790	1.747	1.304
PtAs ₂	1397.244	662.983	227.251	105.569	58.319	36.089	56.979	32.621	11.946	6.113	2.698	1.700	1.272
PdPt ₃ S ₄	1156.842	553.160	228.499	107.460	59.866	37.261	63.636	36.421	13.232	6.678	2.850	1.743	1.275
PtS	1308.261	626.951	218.310	102.902	57.521	35.945	71.582	41.008	14.847	7.433	3.104	1.858	1.335
ID	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	2 MeV	3 MeV	4 MeV	5 MeV	6 MeV	8 MeV	10 MeV	15 MeV	
Pt	2.506	1.814	1.471	1.097	0.970	0.892	0.885	0.900	0.925	0.983	1.045	1.188	
Fe	0.607	0.528	0.472	0.385	0.336	0.285	0.261	0.248	0.241	0.236	0.236	0.244	

Cu	0.681	0.590	0.527	0.429	0.376	0.322	0.297	0.284	0.278	0.275	0.277	0.290
Sb	0.546	0.447	0.388	0.310	0.275	0.247	0.239	0.238	0.241	0.251	0.263	0.291
As	0.433	0.372	0.332	0.270	0.237	0.205	0.191	0.184	0.182	0.182	0.185	0.197
Pd	1.718	1.431	1.255	1.009	0.893	0.795	0.762	0.755	0.759	0.783	0.816	0.897
S	0.168	0.147	0.132	0.108	0.093	0.077	0.068	0.063	0.060	0.056	0.054	0.052
Pt3Fe	2.087	1.529	1.249	0.937	0.828	0.757	0.746	0.756	0.773	0.818	0.867	0.980
PtFe	1.695	1.266	1.046	0.795	0.701	0.634	0.619	0.622	0.633	0.664	0.699	0.784
Pt2CuFe	1.600	1.197	0.990	0.752	0.664	0.601	0.586	0.589	0.599	0.629	0.662	0.743
PtSb2	1.067	0.819	0.688	0.531	0.471	0.428	0.419	0.422	0.429	0.452	0.477	0.535
PtAs2	1.043	0.802	0.674	0.520	0.459	0.412	0.398	0.398	0.402	0.419	0.439	0.488
PdPt3S4	1.027	0.773	0.642	0.489	0.432	0.389	0.378	0.379	0.385	0.402	0.422	0.472
PtS	1.0616	0.7851	0.6449	0.4867	0.4293	0.3892	0.3806	0.3831	0.3902	0.41	0.4322	0.4855

Table (8): The Tenth value layer (TVL, cm) calculated by NGCal software of the tested materials with their basic elements exposed to the photons (the yellow highlight is to distinguish the little decrease of the TVL).

ID	0.015 MeV	0.02 MeV	0.03 MeV	0.04 MeV	0.05 MeV	0.06 MeV	0.08 MeV	0.1 MeV	0.15 MeV	0.2 MeV	0.3 MeV	0.4 MeV	0.5 MeV
Pt	0.001	0.001	0.004	0.009	0.015	0.025	0.012	0.022	0.060	0.121	0.296	0.507	0.719
Fe	0.005	0.011	0.036	0.081	0.149	0.243	0.491	0.787	1.489	2.003	2.661	3.111	3.476
Cu	0.004	0.008	0.024	0.053	0.099	0.162	0.338	0.562	1.162	1.653	2.303	2.738	3.082
Sb	0.007	0.015	0.045	0.017	0.031	0.050	0.108	0.196	0.541	1.017	2.051	2.935	3.639
As	0.004	0.009	0.026	0.059	0.110	0.181	0.387	0.667	1.519	2.317	3.463	4.230	4.822
Pd	0.003	0.006	0.003	0.007	0.012	0.020	0.043	0.078	0.210	0.380	0.713	0.973	1.175
S	0.072	0.166	0.526	1.127	1.902	2.745	4.303	5.507	7.386	8.544	10.196	11.509	12.668
Pt3Fe	0.001	0.002	0.005	0.011	0.019	0.031	0.016	0.027	0.076	0.152	0.367	0.621	0.871
PtFe	0.001	0.002	0.007	0.014	0.025	0.040	0.021	0.037	0.102	0.203	0.479	0.790	1.089
Pt2CuFe	0.001	0.002	0.007	0.015	0.026	0.042	0.023	0.039	0.109	0.216	0.509	0.839	1.154
PtSb2	0.002	0.005	0.013	0.013	0.023	0.037	0.037	0.066	0.182	0.360	0.825	1.318	1.766
PtAs2	0.002	0.004	0.010	0.022	0.040	0.064	0.040	0.071	0.193	0.377	0.854	1.354	1.810
PdPt3S4	0.002	0.004	0.010	0.021	0.039	0.062	0.036	0.063	0.174	0.345	0.808	1.321	1.807
PtS	0.002	0.004	0.011	0.022	0.040	0.064	0.032	0.056	0.155	0.310	0.742	1.240	1.725
ID	0.6 MeV	0.8 MeV	1 MeV	1.5 MeV	2 MeV	3 MeV	4 MeV	5 MeV	6 MeV	8 MeV	10 MeV	15 MeV	
Pt	0.919	1.269	1.565	2.100	2.374	2.580	2.603	2.558	2.490	2.342	2.203	1.939	
Fe	3.796	4.365	4.878	5.989	6.857	8.076	8.829	9.295	9.566	9.777	9.767	9.458	
Cu	3.380	3.902	4.367	5.366	6.129	7.160	7.767	8.112	8.292	8.383	8.305	7.937	
Sb	4.219	5.157	5.934	7.433	8.380	9.332	9.643	9.665	9.560	9.185	8.773	7.906	
As	5.322	6.184	6.944	8.544	9.730	11.253	12.082	12.496	12.679	12.658	12.418	11.696	
Pd	1.340	1.610	1.835	2.283	2.579	2.898	3.022	3.051	3.035	2.940	2.823	2.567	

S	13.729	15.672	17.454	21.420	24.730	29.942	33.780	36.639	38.731	41.475	42.965	44.194
Pt3Fe	1.104	1.506	1.844	2.456	2.780	3.041	3.086	3.047	2.977	2.814	2.656	2.349
PtFe	1.359	1.819	2.200	2.898	3.285	3.630	3.719	3.701	3.638	3.468	3.293	2.937
Pt2CuFe	1.439	1.924	2.326	3.061	3.469	3.834	3.928	3.909	3.842	3.661	3.476	3.101
PtSb2	2.159	2.812	3.349	4.334	4.892	5.386	5.502	5.463	5.362	5.097	4.832	4.303
PtAs2	2.208	2.871	3.417	4.427	5.020	5.594	5.782	5.792	5.724	5.497	5.246	4.720
PdPt3S4	2.242	2.978	3.588	4.705	5.336	5.919	6.087	6.077	5.988	5.728	5.453	4.881
PtS	2.169	2.933	3.570	4.731	5.364	5.916	6.049	6.011	5.902	5.616	5.327	4.743

Table (9): The ($\Delta\%$) values calculated via Equation (4) according to LAC data (Pt and the naturally tested materials) exposed to the photons from the NGCal and MATXCOM calculations.

Energy, MeV	Pt	Pt3Fe	PtFe	Pt2CuFe	PtSb2	PtAs2	PdPt3S4	PtS
0.015	0.129343	0.13148209	0.118542868	0.114893	0.107561	0.186171	0.34324	0.134035
0.02	-0.02758	-29.5997249	-0.0324792	-0.03212	0.089771	-0.06484	0.219374	-0.01982
0.03	-0.05305	-0.04894842	-0.06116767	-0.05579	0.877305	-0.10395	0.202022	-0.04437
0.04	0.152966	0.14731914	0.119260486	0.11476	0.069947	0.042191	0.296956	0.15759
0.05	0.544571	0.53145635	0.489096284	0.474454	0.056323	0.318055	0.606549	0.54303
0.06	1.145946	1.11661124	1.043122822	1.02079	0.225517	0.745672	1.075477	1.135037
0.08	0.237052	0.24166905	0.233140389	0.232282	0.085849	0.199257	0.425942	0.244439
0.1	0.020402	0.02688468	0.021194469	0.020338	-0.0634	-0.00273	0.222347	0.027454
0.15	-0.14869	-0.14042537	-0.14331999	-0.14395	-0.19294	-0.15886	0.058966	-0.1402
0.2	-0.19546	-0.19764582	-0.1899398	-0.19318	-0.18929	-0.19196	0.016738	-0.19154
0.3	-0.0598	-0.05555137	-0.04978064	-0.0644	-0.03029	-0.04867	0.147045	-0.06722
0.4	0.011744	0.00852356	0.021935446	0.029045	0.072393	0.003143	0.224474	0.036151
0.5	0.176165	0.16772525	0.146804641	0.149161	0.133839	0.108628	0.363779	0.155008
0.6	-0.13595	-0.11871902	-0.12808268	-0.1224	-0.04907	-0.01526	0.111014	-0.13044
0.8	0.219469	0.2336634	0.173613523	0.238691	0.22509	0.247526	0.403773	0.268469
1	0.337441	0.28427991	0.232093645	0.288134	0.240148	0.2821	0.431451	0.298337
1.5	0.330672	0.26098686	0.199123753	0.29335	0.246066	0.215464	0.489487	0.354675
2	0.2123	0.28713473	0.281582003	0.254741	0.14132	0.154747	0.348019	0.295418
3	0.269295	0.16003284	0.202759217	0.268657	0.112762	0.142257	0.516937	0.31654
4	0.189953	0.16161089	0.176840763	0.211327	0.114116	0.065923	0.332323	0.166932
5	0.125085	0.21759249	0.174017544	0.190511	0.119425	0.14111	0.240384	0.277543
6	0.171018	0.17792285	0.140188598	0.065537	0.102726	0.066686	0.396674	0.042261
8	0.138269	0.0448042	0.154337122	0.149987	0.169059	0.213333	0.238291	-0.00679
10	0.109214	0.09422697	0.040365265	0.058653	0.112427	0.212023	0.303677	0.051487
15	0.067119	0.11733028	0.111619183	0.071797	0.032342	0.168773	0.37034	0.105781

Table (10a). P% - all the naturally tested materials and their basic elements exposed to neutrons depending on LAC- NGCal data at various thicknesses.

ID	Thermal (25.4 meV)			
	0.5 cm	1 cm	5 cm	10 cm
Pt	29.20062408	49.87448369	96.83557873	99.89986438
Fe	11.8076534	22.22110001	71.5351445	91.89752001
Cu	16.79393964	30.7675152	84.0944169	97.47012426
Sb	7.817511227	15.02388764	55.69178119	80.36781746
As	10.05303796	19.09544019	65.33709185	87.98482798
Pd	21.14425379	37.81771289	90.70320064	99.13569522
S	1.039558845	2.068310864	9.922520259	18.86047644
Pt₃Fe	25.63278501	44.69517335	94.82613399	99.73231111
PtFe	22.29612045	39.62107103	91.97533289	99.35604718
Pt₂CuFe	21.95268963	39.08617344	91.61352587	99.29667052
PtSb₂	14.15355423	26.30387749	78.26181947	95.27451507
PtAs₂	16.5201583	30.31116029	83.56324171	97.29832977
PdPt₃S₄	13.34885883	24.91579733	76.13602055	94.30510485
min	1.039558845	2.068310864	9.922520259	18.86047644
max.	29.20062408	49.87448369	96.83557873	99.89986438

Table (10b). P% - all the naturally tested materials and their basic elements exposed to neutrons depending on LAC- NGCal data at various thicknesses.

ID	Fast (4 MeV)			
	0.5 cm	1 cm	5 cm	10 cm
Pt	0.432561745	0.863252393	4.242382025	8.304785998
Fe	1.685631537	3.342849536	15.63351834	28.82296772
Cu	2.307949825	4.562633325	20.82424043	37.31199096
Sb	0.0099995	0.019998	0.099950017	0.199800133
As	0.139902046	0.279608366	1.390245574	2.76116332
Pd	0.319488546	0.637956362	3.149341792	6.199500047
S	0.014998875	0.0299955	0.149887556	0.29955045
Pt₃Fe	0.683155808	1.361644598	6.62532284	12.81169665
PtFe	0.995511649	1.981112863	9.52078227	18.13511159
Pt₂CuFe	1.061327747	2.111391329	10.12047289	19.21670606
PtSb₂	0.108940617	0.217762553	1.084081025	2.156409734
PtAs₂	0.231731088	0.462925183	2.293294918	4.53399782
PdPt₃S₄	0.18233357	0.364334685	1.808447721	3.58419061
min	0.0099995	0.019998	0.099950017	0.199800133
max.	2.307949825	4.562633325	20.82424043	37.31199096

Table(11a): P% - all the basic elements related to the tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=0.5 cm).

E. MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	100	100	100	100	100	100	99.99998949
0.02	100	100	100	100	100	100	99.90435002
0.03	100	100	100	100	100	100	88.79942422
0.04	100	99.99994098	99.99999997	100	99.99999969	100	64.07906813
0.05	100	99.95617189	99.9992037	100	99.99734667	100	45.49730304
0.06	100	99.14470156	99.92227278	99.99999999	99.83192329	100	34.32980392
0.08	100	90.48732437	96.75681722	99.99765031	94.95758474	99.99996721	23.52337137
0.1	100	76.97190054	87.24995009	99.72614317	82.31662052	99.9748356	18.8913036
0.15	99.99999958	53.92547538	63.0391152	88.18564655	53.25626734	95.40712961	14.43509712
0.2	99.99295424	43.75876617	50.32706656	67.82032037	39.20787935	81.72287668	12.60525229
0.3	97.95648741	35.12092283	39.43118322	42.94274793	28.27996147	59.52557934	10.67689527
0.4	89.6842672	30.92345856	34.3931451	32.41235595	23.81571666	48.39001374	9.513996075
0.5	79.75981093	28.19240963	31.23601143	27.08895139	21.22425176	42.186912	8.682249702
0.6	71.47815782	26.15596854	28.93142997	23.85189561	19.43976335	38.14764426	8.034805392
0.8	59.54581149	23.16346939	25.58480268	19.97091061	16.96973449	32.94788278	7.075235118
1	51.95345705	20.99902565	23.20149407	17.60249264	15.25936947	29.55972512	6.374743079
1.5	42.10273273	17.4689005	19.33375695	14.32464717	12.59039392	24.54999994	5.225992802
2	38.36867981	15.43248698	17.13977219	12.81256853	11.14105845	22.06343816	4.539248306
3	35.9175724	13.26866944	14.86568498	11.58954906	9.709234909	19.90245648	3.764319701
4	35.69289094	12.20011543	13.78620618	11.23431137	9.074982259	19.1686257	3.343332821
5	36.20529546	11.62755738	13.23960958	11.21167324	8.785836552	19.00761111	3.086852967
6	36.96625701	11.31904214	12.97458643	11.33012657	8.665811028	19.09867631	2.921475107
8	38.7985926	11.09128351	12.84438614	11.76531091	8.682249702	19.65738432	2.731987293
10	40.66673049	11.10372986	12.96022605	12.28524002	8.842371806	20.38239904	2.639051971
15	44.76094695	11.44797911	13.52112314	13.54144329	9.365930447	22.17830985	2.56600387

Table (11b): P% - all the naturally tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=0.5 cm).

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	100
0.04	100	100	100	100	100	100	100
0.05	100	100	100	100	100	100	100
0.06	100	100	100	100	99.99999833	99.99999901	99.99999808
0.08	100	100	100	100	100	100	100
0.1	100	100	100	99.9999976	99.99999176	99.99999872	99.99999987
0.15	99.99997647	99.99877991	99.99756018	99.82152912	99.74774879	99.86558588	99.94091805
0.2	99.95032879	99.66372628	99.52470985	95.9481637	95.32293776	96.4509847	97.58507028
0.3	95.65437242	90.97796259	89.59620976	75.22908492	74.06300868	75.90100385	78.83878159
0.4	84.35470573	76.69494742	74.64007465	58.2303422	57.25850681	58.08389226	60.4854015
0.5	73.25974291	65.21555911	63.06460941	47.84760081	47.03294132	47.00645117	48.64973043

E. MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.6	64.81322907	57.19434646	55.11201403	41.34515467	40.63705644	40.13032084	41.22772759
0.8	53.35012788	46.84723181	44.95394569	33.53535275	32.9679954	31.95493638	32.39579495
1	46.33987438	40.66673049	38.95140502	29.03617884	28.53768942	27.34877976	27.493937
1.5	37.34332713	32.73297233	31.27107212	23.279405	22.8562792	21.6120524	21.53362524
2	33.83377172	29.49594781	28.1794831	20.94291504	20.46714665	19.34585598	19.2651615
3	31.47694993	27.13049884	25.88112776	19.22478398	18.57599054	17.59301638	17.63420957
4	31.09903484	26.581923	25.3604755	18.86047644	18.04501067	17.17994966	17.30408661
5	31.40839261	26.69196756	25.47235086	18.98209448	18.00402293	17.22134933	17.38674118
6	32.02294743	27.09405498	25.88112776	19.30551883	18.20875684	17.42803749	17.71653419
8	33.56857677	28.21538438	26.94809718	20.18829396	18.86047644	18.167851	18.53526836
10	35.14395082	29.49594781	28.1794831	21.17973089	19.66782818	18.98209448	19.42646981
15	38.7067216	32.39579495	30.99560584	23.47096694	21.6120524	20.94291504	21.53362524

Table (12a): P% - all the basic elements related to the tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=1 cm).

E, MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	99.99990851
0.03	100	100	100	100	100	100	98.74547102
0.04	100	100	100	100	100	100	87.09686654
0.05	100	99.99998079	99.99999999	100	99.99999993	100	70.29456024
0.06	100	99.99268465	99.99993958	100	99.9997175	100	56.87425347
0.08	100	99.09509002	99.89481765	99.99999994	99.74574048	100	41.51325274
0.1	100	94.69706635	98.37436227	99.99925002	96.8729809	99.99999367	34.21379368
0.15	100	78.77138181	86.33892995	98.60421053	78.15023457	99.78905542	26.78647395
0.2	99.9999995	68.36923617	75.32599683	89.64468219	63.04318067	96.65946763	23.62158073
0.3	99.95824056	57.90705346	63.31418434	67.44469986	48.56236073	83.61821272	20.21382962
0.4	98.93585657	52.28431423	56.9574059	54.31910372	41.95954973	73.36409318	18.12283094
0.5	95.90334746	48.43669965	52.71513876	46.8397899	37.9438149	66.57646856	16.61068481
0.6	91.86504519	45.47059017	49.49258355	42.01466197	35.10048271	61.7428609	15.42402981
0.8	83.63458632	40.96147565	44.62378408	35.95344851	31.0597501	55.04013576	13.64988072
1	76.9152971	37.58846051	41.01989486	32.10650781	28.19025537	50.38167674	12.34311266
1.5	66.47906443	31.88617615	34.92957233	26.59733917	23.59560765	43.07297491	10.1788756
2	62.01580371	28.48335742	31.34182647	23.98351794	21.04088507	39.25892329	8.87244886
3	58.93442472	24.77676299	27.52148407	21.83592164	18.47577739	35.84383521	7.386938373
4	58.64595724	22.91180269	25.67181755	21.20652523	17.32641149	34.66288928	6.574886898
5	59.30235672	21.90311385	24.72634654	21.16633031	16.79976386	34.40232941	6.078419322
6	60.26747245	21.35687713	24.26577393	21.37653546	16.58065925	34.54975825	5.757600046
8	62.54387732	20.95240132	24.03898972	22.14639642	16.61068481	35.45064106	5.38933704
10	64.79563129	20.97453155	24.24077751	23.06120882	16.90286822	36.61037617	5.208457989
5	69.48647018	21.58539596	25.21403857	25.24917971	17.85465436	39.43784543	5.066163982

Table (12b): P% - all the naturally tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=1 cm).

E, MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	100
0.04	100	100	100	100	100	100	100
0.05	100	100	100	100	100	100	100
0.06	100	100	100	100	100	100	100
0.08	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100
0.15	100	99.99999999	99.99999994	99.99968148	99.99936369	99.99981933	99.99996509
0.2	99.99997533	99.9988692	99.99774099	99.83582623	99.78125089	99.8740449	99.94168114
0.3	99.81115521	99.18602841	98.91761149	93.86401766	93.27272481	94.19238385	95.52202836
0.4	97.55224767	94.56874524	93.56874186	82.55295687	81.73164759	82.43039912	84.38596505
0.5	92.84958651	87.90042672	86.35776922	72.80127259	71.94490695	71.91683782	73.63149815
0.6	87.61891152	81.67676025	79.85068715	65.59609119	64.76040931	64.15621517	65.45819996
0.8	78.23789431	71.74783234	69.69931905	55.82450666	55.06710359	53.69869317	54.2967146
1	71.20590919	64.79563129	62.73069051	49.64136087	48.93138166	47.21800198	47.42870828
1.5	60.74141345	54.75146988	52.76334473	41.13950303	40.48846341	38.55329671	38.43028032
2	56.22030235	50.29178625	48.41813352	37.49977317	36.74525238	34.94909053	34.81885852
3	53.0459161	46.90035801	45.06392778	34.75364478	33.70130684	32.09089051	32.15876567
4	52.52657001	46.09785969	44.28941382	34.16377716	32.83379723	31.40839261	31.61385908
5	52.95191396	46.2593238	44.45629513	34.36098986	32.76659744	31.47694993	31.75049468
6	53.79120324	46.84723181	45.06392778	34.88400708	33.10192543	31.81871007	32.29431255
8	55.86866007	48.4696896	46.63419495	36.30091578	34.16377716	33.0349939	33.63497499
10	57.93692885	50.29178625	48.41813352	37.87365178	35.46742171	34.36098986	35.07906233
15	62.43134023	54.2967146	52.38393587	41.43307099	38.55329671	37.49977317	38.43028032

Table (13a): P% - all the basic elements related to the tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=5 cm).

E, MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	99.99999997
0.04	100	100	100	100	100	100	99.99642335
0.05	100	100	100	100	100	100	99.76869771
0.06	100	100	100	100	100	100	98.50829437
0.08	100	99.99999999	100	100	100	100	93.15635704
0.1	100	99.99995806	99.99999989	100	99.99999701	100	87.67819834
0.15	100	99.95688696	99.99524201	99.99999995	99.95019948	100	78.964317
0.2	100	99.68337267	99.90854697	99.99880926	99.31059737	99.99999584	74.00718416
0.3	100	98.67856246	99.33550626	99.63431385	96.39914907	99.98820205	67.66758828

0.4	99.99999999	97.52653454	98.52262009	98.01082459	93.4135126	99.8659282	63.20285775
0.5	99.99998846	96.35494962	97.63620073	95.75445505	90.79708588	99.58287937	59.67707418
0.6	99.99964373	95.17881289	96.71318114	93.44472423	88.48650085	99.18047454	56.7252127
0.8	99.9882609	92.82738583	94.7926547	89.22347469	84.42728747	98.16293317	51.99187891
1	99.93444264	90.53055607	92.86280255	85.57417236	80.90512096	96.99246687	48.24763218
1.5	99.5767659	85.33857073	88.33409849	78.69119887	73.96295879	94.0214971	41.53547348
2	99.20929459	81.29164555	84.7432781	74.61724044	69.30897747	91.73177226	37.15821704
3	98.8321433	75.91425466	79.99924174	70.82330757	63.98915346	89.13094038	31.86642027
4	98.79054459	72.77678271	77.31349655	69.62954727	61.37807247	88.09307473	28.82652649
5	98.88353194	70.948498	75.83343211	69.55200379	60.13215194	87.85375357	26.91521643
6	99.00978166	69.91820456	75.08499616	69.95578332	59.60442756	87.98963309	25.65843727
8	99.26275117	69.13662561	74.70971864	71.39818475	59.67707418	88.7937665	24.19455029
10	99.45926709	69.1798041	75.04385247	73.03957133	60.37856792	89.76492869	23.46714039
15	99.73547772	70.35272588	76.60621974	76.66113058	62.5962792	91.8528336	22.89098607

Table (13b): P% - all the naturally tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=5 cm).

E, MeV	Pt₃Fe	PtFe	Pt₂CuFe	PtSb₂	PtAs₂	PdPt₃S₄	PtS
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	100
0.04	100	100	100	100	100	100	100
0.05	100	100	100	100	100	100	100
0.06	100	100	100	100	100	100	100
0.08	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100
0.15	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100
0.3	100	100	99.99999999	99.99991302	99.99986222	99.99993393	99.99998199
0.4	99.99999912	99.99995274	99.99988998	99.98383375	99.97965316	99.98325792	99.99071941
0.5	99.99981308	99.99740671	99.99527473	99.85115203	99.82619648	99.82532529	99.87252434
0.6	99.99709066	99.97934566	99.96678753	99.51800899	99.45655665	99.40834395	99.50827212
0.8	99.95119048	99.82000565	99.74457586	98.31768607	98.16843611	97.87202636	98.00594514
1	99.80206762	99.45926709	99.28095391	96.76130592	96.52647411	95.90334746	95.98446662
1.5	99.06744749	98.10319634	97.64822541	92.93487869	92.53541239	91.2402253	91.1521881
2	98.39171212	96.96512516	96.34838262	90.46308378	89.87335381	88.35158422	88.2345157
3	97.71773086	95.77858582	94.99633729	88.17554096	87.19071644	85.55757312	85.62960502
4	97.58868996	95.44980456	94.63353081	87.63128642	86.33045746	84.81709406	85.04313808
5	97.69479367	95.51754814	94.71342713	87.81543257	86.26193859	84.89281912	85.19196134
6	97.89320005	95.75742589	94.99633729	88.2931963	86.60113253	85.26581674	85.77259284
8	98.32607664	96.36659514	95.67172021	89.51264563	87.63128642	86.53397043	87.12650964
10	98.68324525	96.96512516	96.34838262	90.74494225	88.80832514	87.81543257	88.4674879
1	99.25160908	98.00594514	97.55224767	93.10931716	91.2402253	90.46308378	91.1521881

Table (14a): P% - all the basic elements related to the tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=10 cm).

E, MeV	Pt	Fe	Cu	Sb	As	Pd	S
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	100
0.04	100	100	100	100	100	100	99.9999987
0.05	100	100	100	100	100	100	99.99946499
0.06	100	100	100	100	100	100	99.97774814
0.08	100	100	100	100	100	100	99.53164551
0.1	100	100	100	100	100	100	98.48173204
0.15	100	99.9998141	99.9999977	100	99.9999752	100	95.57500041
0.2	100	99.99899747	99.99991636	99.99999999	99.99524724	100	93.24373525
0.3	100	99.98253803	99.99558448	99.99866274	99.87033873	99.99999861	89.54615152
0.4	100	99.93881969	99.97817349	99.96043181	99.56618184	99.99982025	86.45970322
0.5	100	99.86713608	99.94412453	99.81975348	99.15306372	99.9982601	83.74061654
0.6	100	99.76756155	99.89196822	99.5702836	98.67439337	99.99328378	81.27292784
0.8	99.99999862	99.48553606	99.72883555	98.83866502	97.57490624	99.96625185	76.95220309
1	99.99995702	99.10329632	99.49060412	97.91895497	96.35385594	99.90954744	73.21692425
1.5	99.99820873	97.85042492	98.63906742	95.45934994	93.22072485	99.64257503	65.81899139
2	99.99374785	96.49997474	97.67232437	93.55715517	90.58061136	99.3163641	60.50910314
3	99.98636111	94.19876871	95.99969669	91.48720619	87.03218931	98.81863543	53.57815314
4	99.98537218	92.5889644	94.85322561	90.77635601	85.08346714	98.58225131	49.34336668
5	99.98753499	91.56010231	94.15976996	90.72919527	84.10554691	98.52468698	46.58614411
6	99.99019468	90.95085583	93.79242583	90.97345044	83.68197727	98.55751087	44.73332051
8	99.99456464	90.47452121	93.60401669	91.81936165	83.74061654	98.74420331	42.53533794
10	99.99707608	90.50115525	93.771907	92.73135286	84.3014212	98.95243315	41.427214
15	99.99930028	91.21039137	94.52731045	94.55297174	86.00961671	99.3362368	40.5419997

Table (14b): P% - all the naturally tested materials, which exposed to photons depending on LAC- MATXCOM data at (x=10 cm).

E, MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.015	100	100	100	100	100	100	100
0.02	100	100	100	100	100	100	100
0.03	100	100	100	100	100	100	100
0.04	100	100	100	100	100	100	100
0.05	100	100	100	100	100	100	100
0.06	100	100	100	100	100	100	100
0.08	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100
0.15	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100

E, MeV	Pt ₃ Fe	PtFe	Pt ₂ CuFe	PtSb ₂	PtAs ₂	PdPt ₃ S ₄	PtS
0.4	100	100	100	99.99999739	99.99999586	99.9999972	99.99999914
0.5	100	99.99999993	99.99999978	99.99977844	99.99969792	99.99969489	99.9998375
0.6	99.99999992	99.99999573	99.99998897	99.99767685	99.99704669	99.99649943	99.99758204
0.8	99.99997618	99.99967602	99.99934759	99.9716982	99.96645374	99.95471728	99.96023745
1	99.99960823	99.99707608	99.99482973	99.89510861	99.87934618	99.83217438	99.83875492
1.5	99.99130346	99.96402136	99.94469156	99.50084061	99.44279932	99.23266347	99.21716225
2	99.9741341	99.90789535	99.86665691	99.09047229	98.97451037	98.6431441	98.61573379
3	99.94791248	99.82179662	99.74963359	98.60182168	98.35922255	97.91416306	97.93491748
4	99.94185584	99.79295721	99.71201008	98.47014924	98.13143607	97.69479367	97.76292281
5	99.94686024	99.79907625	99.72052147	98.51536317	98.11265669	97.71773086	97.80721991
6	99.95561394	99.82000565	99.74963359	98.62950747	98.20470351	97.82903844	97.97580886
8	99.97197981	99.86798369	99.81265994	98.90015398	98.47014924	98.18666048	98.34273246
10	99.98266157	99.90789535	99.86665691	99.14343906	98.74746414	98.51536317	98.67001165

3. Results and Discussion

Today, lead metal or its alloys are the most preferred protector against harmful exposure even with its high toxicity. Currently, researchers are working to develop new materials for this purpose or evaluate the natural and denser solid materials that their components have high atomic numbers [6-10, 12, 32, 33]. In the present study, two calculation methods (NGCal and MATXCOM) have been applied to estimate the LAC, MAC, TVL attenuation factors. The percentages of difference ($\Delta\%$) of all the tested materials at each energy value have been calculated based on LAC data and (Equation 4, Table 9) [29-31]. In general, Table (9) shows that minimum ($\Delta\%$) is -29.5997 whereas maximum ($\Delta\%$) is 1.145946 which are acceptable variation and confirms the high accuracy and precision of both calculation models.

Moreover, the Protection Efficiency (P%) was calculated (Equation 5) according to the Beer-Lamberts law (Equation 1), LAC data, and the hypothesized shielding thickness $x = (0.5, 1, 5, \text{ and } 10)$ cm (Tables 10-14). In this study, seven naturally occurring Platinum - metallic alloys and their basic elements have been investigated for their photon or neutron attenuation characters. For this aim, LAC, MAC, and TVL were calculated via MATXCOM - NGCal models and Lambert-Beer Law at energy range (0.015 – 15) MeV.

These naturally occurring Pt-metallic materials are extremely rare in the Earth's crust. The Platinum has an average abundance (~0.005 ppm) in the forms of Pt-Fe alloys, sulfides, and arsenides in the ore deposits. Furthermore, the average earth abundance of the iron, copper, antimony, arsenic, palladium, Sulfur, and isoferroplatinum are (56300, 50, 0.2, 1.5, 0.015, 350, and 0.05) ppm respectively. In addition, these seven Pt-based materials represent the major mined sources with low crustal abundance [27]. The choosing of these natural materials is more beneficial than the using of the prepared materials whereas time, cost, chemicals, preparation methods, technical characterization, and environmental concerns are minimized to more acceptable levels. This study is the first Iraqi attempt to calculated attenuation factors via MATXCOM in addition to the comparison with the NGCal software results of the same naturally occurring Pt-metallic materials and their basic elements.

In general, the decrease or increase of density, mean atomic number, P% against fast neutrons, thermal neutrons, and photons are as follows:

- The increase of the density (Table 1).
 - ❖ S, As, Sb, Fe, Cu, PtS, PdPt₃S₄, PtAs₂, PtSb₂, Pd, Pt₂CuFe, PtFe, Pt₃Fe, Pt.
 - ❖ PtS, PdPt₃S₄, PtAs₂, PtSb₂, Pt₂CuFe, PtFe, Pt₃Fe.
 - ❖ S, As, Sb, Fe, Cu, Pd, Pt.
- The decrease of the mean atomic number (Table 1).

- ❖ Pt₃Fe, PtSb₂, Pt₂CuFe, PtFe, PtAs₂, PtS, PdPt₃S₄.
 - ❖ Pt, Sb, Pd, As, Cu, Fe, S.
 - ❖ Pt, Pt₃Fe, PtSb₂, Pt₂CuFe, PtFe, Sb, PtAs₂, PtS, Pd, PdPt₃S₄, As, Cu, Fe, S.
- The sequence of the P% increase - thermal neutrons - NGCal model (Table 10) as follows:
- ❖ PtS, PdPt₃S₄, PtSb₂, PtAs₂, Pt₂CuFe, PtFe, Pt₃Fe.
 - ❖ S, Sb, As, Fe, PdPt₃S₄, PtSb₂, PtAs₂, Cu, Pd, Pt₂CuFe, PtFe, Pt₃Fe, Pt.
- The sequence of the P% increase - fast neutrons - NGCal model (Table 10) as follows:
- ❖ PtSb₂, PtS, PdPt₃S₄, PtAs₂, Pt, Pt₃Fe, PtFe, Pt₂CuFe.
 - ❖ Sb, S, PtSb₂, As, PdPt₃S₄, PtAs₂, Pd, Pt, Pt₃Fe, PtFe, Pt₂CuFe, Fe, Cu.
 - ❖ Sb, S, As, Pd, Pt, Fe, Cu.

The differences between the fast neutron and thermal neutron interaction with each tested material is due to the huge energy difference where the fast neutron has the energy of 4 MeV that is approximately 157 million times larger than thermal neutron with 25.4 meV (or 2.54×10^{-8} MeV).

- The sequence of the P% increase - photons as follows (Tables 11-14), Figures (6 and 7).
- ❖ PtSb₂, PdPt₃S₄, PtS, PtAs₂, Pt₂CuFe, PtFe, Pt₃Fe.
 - ❖ S, As, Fe, Cu, Sb, PdPt₃S₄, PtS, PtAs₂, PtSb₂, Pt₂CuFe, PtFe, Pd, Pt₃Fe, Pt.

Here, the P% results have the same ($\Delta\%$) results by comparing both models depending on the same ($\Delta\%$) –LAC, ($\Delta\%$)-MAC, or ($\Delta\%$)-TVL bases. It means that ($\Delta\%$) can be calculated depending on LAC, MAC, or TVL data of MATXCOM and NGCal or any other models and gives the same ($\Delta\%$) results because all these factor are related to each other and depending on the energy of the incident photon or neutron and The Lambert –Beer equation (Equations 1-3)[31]. From Tables (3, 4, and 5), each attenuation character has a general trend of increasing (TVL) or decreasing (LAC or MAC). Tables (3 and 4) show that Pt has a little rise at 0.08 MeV then decrease whereas Sb or Pd has this rise at 0.04 MeV or 0.03 MeV respectively. All the Platinum – metallic materials have their rise at the 0.08 MeV except PtSb₂ at the 0.03 MeV reflecting the important presence of Pt on their chemical structures to attenuate the incident photon. It is known that this trend changing of each character is due to photoelectric absorption edges at a specific energy which is related to the binding energies of the electronic shells K, L, M, ... etc. In general physics or chemistry, the probability is important factor and it decreases rapidly with the increasing of the photon energy but at higher energy, the electron orbitals are much bigger than these interaction probabilities leading to reduction of the overall probabilities. Here, the photon does not have the required energy to eject the electron from that K- or L- shell. At high energy that this threshold, the photon can easily interact and cause a sharp change in the attenuation character(s) then gain the general trend (decrease (LAC or MAC) or increase (TVL) [34]. Table (1) shows that all the Platinum metallic materials, has Pt with the highest elemental fraction except PtSb₂ that Sb fraction is higher than Pt. From this important point, these high Pt fraction materials are more influenced by the electronic configuration of Pt and its elemental fraction whereas PtSb₂ is more governed by electronic configuration of Sb and its elemental fraction in the PtSb₂ and directing this trend change at the energy 0.03 MeV or 0.08 MeV (Figures 1, 6, 7, Tables 3-5).

Sulphur (₁₆S). [Ne] 3s² 3p⁴

Copper (₂₉Cu). [Ar] 3d¹⁰ 4s¹

Iron (₂₆Fe). [Ar] 3d⁶ 4s²

Arsenic (₃₃As). [Ar] 3d¹⁰ 4s² 4p³

Palladium (₄₆Pd).[Kr] 4d¹⁰

Antimony (₅₁Sb). [Kr] 4d¹⁰ 5s² 5p³

Platinum (₇₈Pt). [Xe] 4f¹⁴ 5d⁹ 6s¹

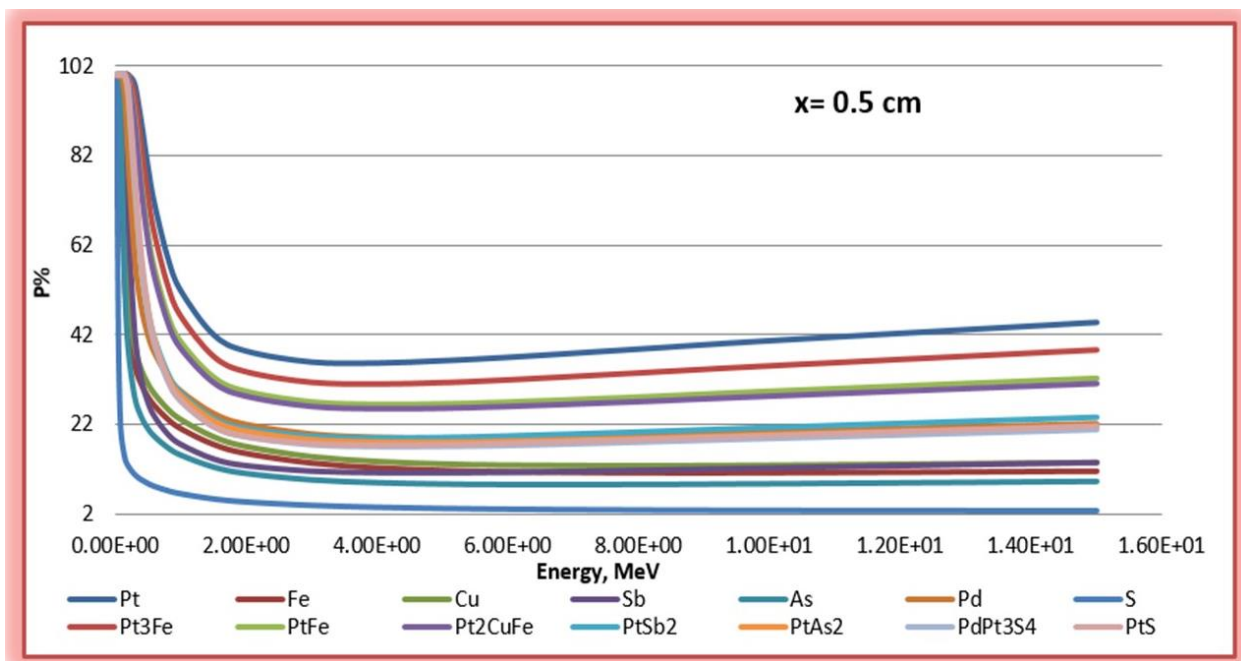


Figure (5a): P% of all the tested materials (x= 0.5 cm).

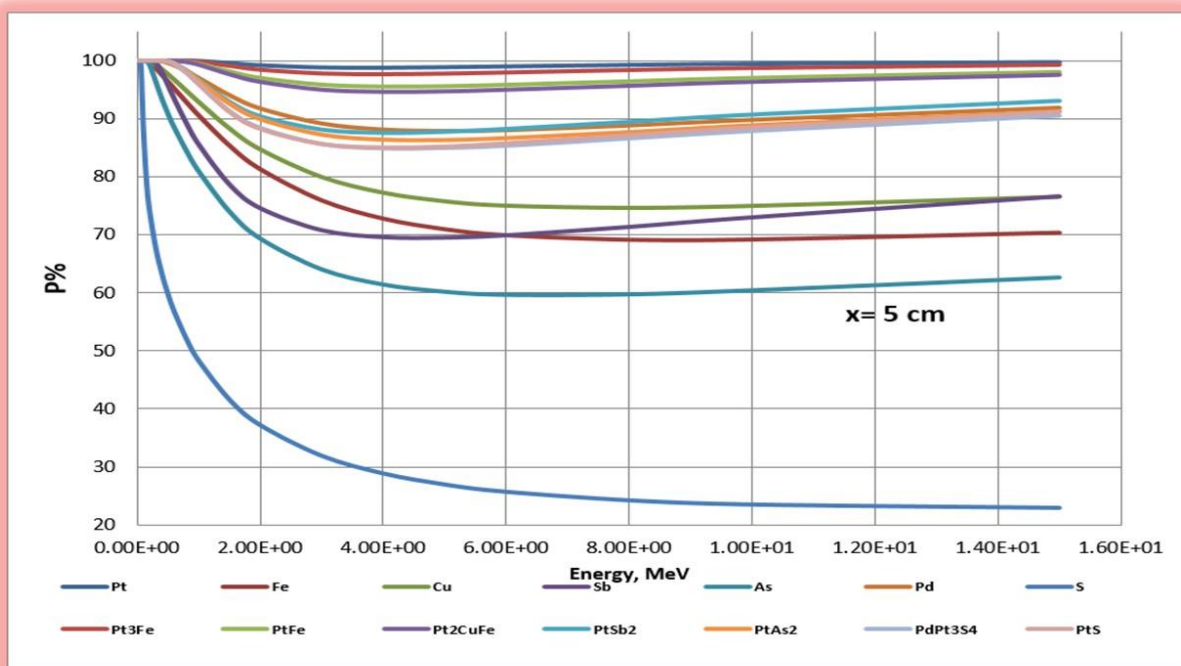


Figure (5b): P% of all the tested materials (x=5 cm).

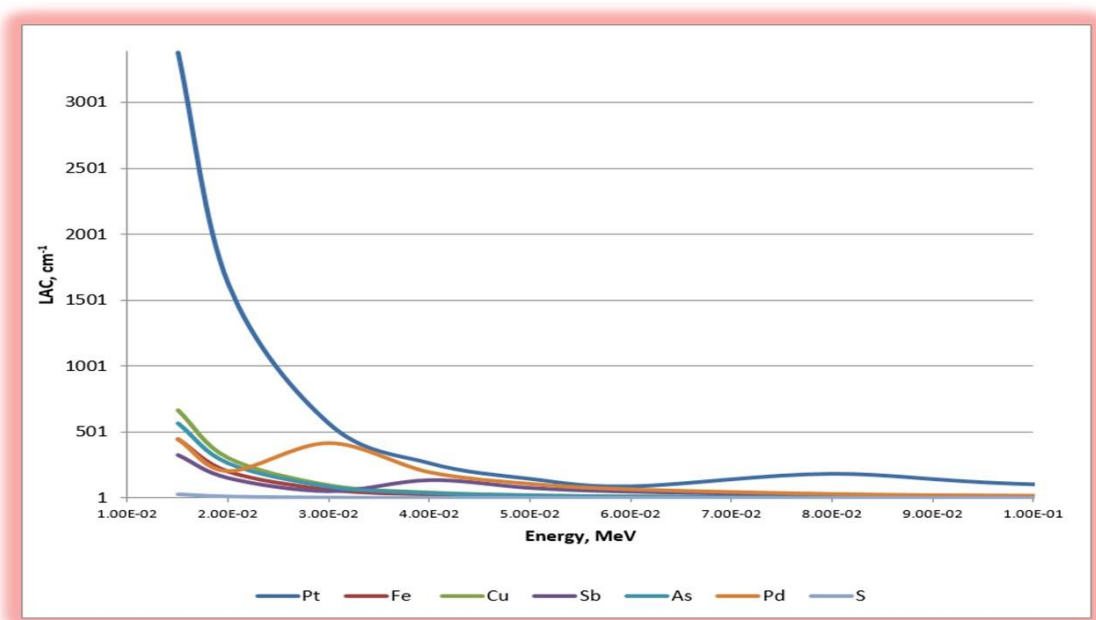


Figure (6): The LAC of the basic elements (Energy: 0.015 MeV to 0.15 MeV).

Between all the tested naturally occurred materials, the **Pt₃Fe** was found to be the superior photon or thermal neutron shielding protector due to higher LAC and MAC and lower TVL at the applied photon energy whereas **Pt₂CuFe** was superior fast neutron shielding material. This conclusion is based on the obtained LAC, MAC, TVL, and P% data (Tables 2-14). In addition, density, mean atomic number, and crystal system are essential factors that influence the interactions between each material and the incident photon (X-rays or gamma rays) or the neutrons (Tables 1).

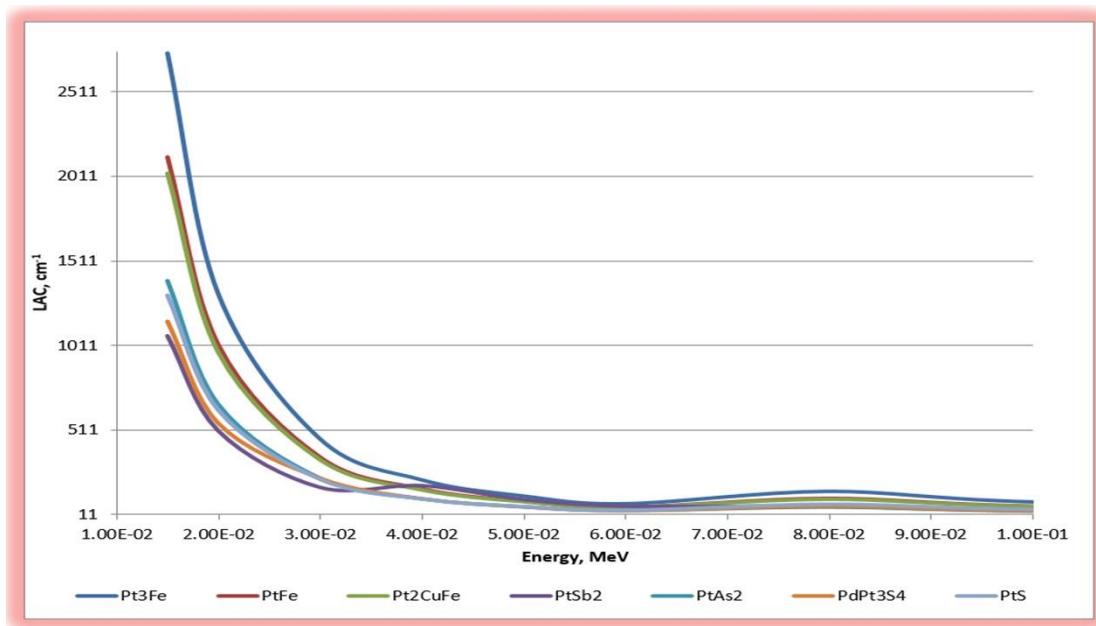


Figure (7): The LAC of the platinum metallic materials (Energy: 0.015 MeV to 0.15 MeV).

4. Conclusions

The current study explores the attenuation nature of seven naturally occurred platinum materials against neutron and photon exposure via two theoretical models at standard energy range (0.015-15) MeV. MATXCOM and NGCal were applied to calculate LAC, MAC, and TVL factors of these seven materials then compared with their basic elements (Pt, Fe, Cu, Sb, As, Pd, and S). Furthermore, protection efficiency (P%) of all the tested materials

and their basic elements was calculated to define the best shielding materials against neutron or photon exposure. Between all the tested naturally occurred materials, the Pt_3Fe was found to be the superior photon or thermal neutron shielding protector due to higher LAC and MAC and lower TVL at the applied photon energy whereas Pt_2CuFe was superior fast neutron shielding material. This conclusion is based on the obtained LAC, MAC, TVL, and P% data. In addition, density, mean atomic number, and crystal system are essential factors that influence the interactions between each material and the incident photons or the neutrons.

Conflict of Interest: The authors declare that there are no conflicts of interest associated with this research project. We have no financial or personal relationships that could potentially bias our work or influence the interpretation of the results.

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