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STUDIES ON ATTENUATION CROSS SECTION PARAMETERS OF SOME SHAPE MEMORY ALLOYS IN THE ENERGY RANGE 356 KEV 1330 KEV

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ABSTRACT

Mass attenuation of five Shape Memory Alloy's (SMA's) such as Aluminum-Nickel (AlNi), Iron- Titanium (FeTi), Zinc Copper (ZnCu), Copper-Tin (CuSn), Stainless-Steel (Fe CrNiMo), has been calculated at 356 keV- 1330 keV photon energies and compared with Win XCOM data. It is observed that there is good agreement between experimental and theoretical values. The gamma rays were detected using NaI (Tl) scintillation detection system with a resolution of 8.2% at 662 keV. Other related parameters of Shape Memory Alloy's (SMA's) were determined experimentally and theoretically using the obtained values of mass attenuation coefficients and their variations with photon energy have been plotted. The transmission curve shows that the variation of all sample materials initially decreases with increasing photon energy. Investigated samples are good materials for biomedical, medical and biological, sensor/actuator, coupling and other applications.

KEYWORDS : Mass attenuation coefficient, Total atomic cross section, Total electronic cross section, Effective atomic number

The study on the transmission and absorption of X-rays or gamma rays in biological shielding and dosimetric materials assumed high applications in the field of medical physics, medical biology and bio-engineering (Kaewkhao et al., 2008). A large number of photon attenuation measurements and calculations have been made for different materials and the attenuation coefficient has been studied as a function of different parameters. The exact values of the mass attenuation coefficient for X-ray and gamma ray in different materials are very important in various fields such as medical, agriculture, industrial, biological, computerized tomography, nuclear radiation physics and radiation dosimetry (Han and Demir., 2009). The mass attenuation coefficient is key parameter in the primary physics and many applied fields. Mass attenuation coefficient (m) is a measure of the probability of interaction that occurs between incident photons and samples mass per unit area. Mass This parameter is needed to understand the diffusion and transmission of X-ray and γ ray in the material (Manohara and Hanagodimath., 2007). Some of the authors were represented the table in the form of tabulation for all elements and developed new computer program i.e. WinXCOM program (Hubbell, 1982, Hubbell and Seltzer; 1995, Berger and Hubbell, 1987, Gerward et al., 2001). Many research papers are available on theoretical and experimental investigations of mass attenuation coefficient (μ_m) values in a variety of elements and compounds/ mixtures.

Mass attenuation coefficients (μ_m) values are broadly used in research for solving different problems in radiation physics and radiation chemistry (Kaewkhao et al., 2008). It is well known fact that the mass attenuation coefficients strongly depend on the nature of the material, photon energy and density (Baltas et al., 2007). Mass attenuation coefficient data can be used for the determination of some parameters i.e. effective atomic numbers (Z_{eff}), effective electron density (N_{eff}), molar extinction coefficient (ε), mass energy absorption coefficient ($\mu_{en/\rho}$) and effective atomic energy absorption cross section ($\sigma_{a,en}$) of compound materials (El-Kateb et al.; 2000, Kiran Kumar and Venkata Reddy; 1997, Limkitjaroenporn et al., 2013, Murthy, 2004, Gowda et al., 2005, Yasaka et al., 2014, Han et al., 2009. Kore and Pawar, 2014, Kore et al., 2016, Pawar and Bichile, 2013, Ladhaf and Pawar., 2015, Gaikwad et al., 2016, Awasarmol et al., 2017a, Awasarmol et al., 2017b, Awasarmol, 2017c, Awasarmol et al., 2017d). The scattering and absorption of X-rays or gamma ray radiations are related to the density and effective atomic number of an element. In composite materials, a single number cannot represent atomic numbers uniquely across the entire energy range. The number represent an atomic number in compounds is called the effective atomic number and varies with the energy (Jackson and Hawkes., 1981). Hine., 1952 stated that the effective atomic numbers (Z_{eff}) play a key role in photon interactions for compound materials. Correct values of Z_{eff} are mostly used in the many fields i.e. medical physics, radiation shielding, pharmaceutical and radiation

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dosimetry. Thus, the theoretical and experimental studies on the interaction of X-ray and gamma rays have fascinated many research groups (Hubbell, 1999. Kurudirek et al., 2015. Chanthima et al., 2012, Chanthima and Kaewkhao, 2013, Demir et al., 2012, Salehi et al., 2015).

During the last decade smart materials and structures have received increasing attention because due to their enormous technological and scientific consequence. Shape Memory Alloy's (SMA's) are the most important branch from the smart / intelligence materials (Satish et al., 2013). SMA's are basically functional materials which exhibit peculiar thermo mechanical properties such as shape memory effect and the super elasticity. These properties are significant as a reversible thermo elastic martensitic transformation occurring at the solid state. The martensite phase shows that the strong amplitude- dependent internal friction, when SMA is used as actuater, it can be classified into "Smart Materials" because which can be combines both actuators and sensor functions. SMA alloys are most commonly used in commercial fields such as biomedical (i.e. stents, surgical tools), sensor/actuator (valves), coupling (i.e. electric fastener, pipe fastener), sport, antennas, gadgets, manufactures etc (Kumar and Lagoudas , 2008).

In literature, we observed that the experimental data is not available on the study of some shape memory alloys. The main purpose of the present study, we have measured the mass attenuation coefficient of some shape memory alloys and related parameters in the energy region 356 keV to 1330 keV by using the transmission method and compared with Win XCOM data.

CALCULATION METHODS

Calculation of Mass Attenuation Coefficient (μ_m)

The mass attenuation coefficients for the compound materials and energies are determined by the transmission experiment. This process described by the following equation:

$$I = I_0 \exp(-\mu_m t) \quad (1)$$

where I_0 and I are the unattenuated and attenuated photon intensities respectively, μm (cm^2gm^{-1}) is mass attenuation coefficient of the material and t (g/cm^2) is the sample thickness.

The photon mass attenuation coefficient for compound or mixture of element is given by mixture rule:

$$\mu_m = \sum iW_i (\mu_m)_i \quad (2)$$

where Wi and (μ_m)i are the weight fraction and mass attenuation coefficient of the i^{th} constituent element, respectively. For a chemical compounds, the fraction by weight (Wi) is represented by following expression:

$$W_i = \frac{n_i A_i}{\sum_j n_j A_j} \quad (3)$$

where A_i is the atomic weight of the i^{th} element, n_i is the number of formula units, ∑jnj is the total number of atoms present in the molecular formula and Aj is the molecular weight of the j^{th} constituent elements.

Calculation of Total Atomic Cross Section ($\sigma_{t,a}$)

The total atomic cross section can be derived by following equation:

$$\sigma_{t,a} = \frac{1}{N_A} \frac{\mu m}{\sum i W_i / A_i} \quad (4)$$

where NA is the Avogadro's number, μm is the mass attenuation coefficient.

Calculation Of Total Electronic Cross Section ($\sigma_{t,el}$)

The total electronic cross section is determined by,

$$\sigma_{t,el} = \frac{1}{N_A} \sum_i \frac{f_i A_i}{Z_i} (\mu m)_i \quad (5)$$

where f_i is the number fraction of atoms of element i and Zi is the atomic number of the i^{th} element in the mixture or compound.

Calculation of Effective Atomic Number (Z_{eff})

The effective atomic number is determined by the following equation:

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad (6)$$

where $\sigma_{t,a}$ and $\sigma_{t,el}$ are the total atomic cross section and total electronic cross section, respectively.

Calculation of Effective Electron Densities (N_{eff})

The effective electron density (N_{eff}) can be determined by the following equation:

$$N_{eff} = \frac{\mu m}{\sigma_e} = \frac{N_A}{M} Z_{eff} \sum_i n_i \quad (7)$$

where μ_m and M/n are the mass attenuation coefficient and average atomic weight respectively, ∑i ni = n is the total number of atoms.

Molar Extinction Coefficien

The value of were determined using the following equation:

$$\varepsilon = 0.4343 \times N_A \times \sigma_{t,a} \quad (8)$$

where, N_A is the Avogadro's number = 6.0248610^{23}, $\sigma_{t,a}$ is the total atomic cross section.

EXPERIMENTAL DETAILS

The mass attenuation coefficients were determined by the transmission method of the narrow beam good geometry set-up. The transmission experiments as shown in Fig.1. In the present work, we used the five radioactive sources ^{133}Ba, ^{137}Cs, ^{54}Mn^{60}, Co, and ^{22}Na. These all radioactive sources are provided by Bhabha Atomic Research Center, Mumbai, for the experimental work. The five radioactive sources emitted gamma ray photon energies at 356, 511, 662, 840, 1170, 1275 and 1330 keV and the sample was placed step by step between the source and detector. The radioactive sources were collimated and detected by (2″×2″) NaI (Tl) scintillation detector with resolution 8.2% at 662 keV and the signals at the detector were amplified and analyzed by the 8K multichannel analyzer.

The shape memory alloys materials viz. Aluminum-Nickel (AlNi), Iron- Titanium (FeTi), Zinc Copper (ZnCu), Copper-Tin (CuSn), Stainless-Steel (Fe CrNiMo), were weighed in a sensitive digital balance with accuracy 0.001mg and the plastic container was used as sample holder, and attenuation of a photon by unfilled container were found to be negligible (Pawar and Bichile; 2013). The transmitted intensity of photo peak was measured to minimize both contributions of small angle and multiple scattering within the full width at half maxima. For more accuracy, a thickness of the sample was selected as per Creagh (1987) criteria 2 < ln (I0 /I) < 4. More information about the experimental arrangement has been reported in our previous work by (Awasarmol et al.: 2017a, Awasarmol et al., 2017b, Awasarmol, 2017c, Awasarmol et al., 2017d).

RESULTS AND DISCUSSION

This paper present the experimental and theoretical values of (μ_m), ($\sigma_{t,a}$), ($\sigma_{t,el}$), (Z_{eff}), (N_{eff}) and (ε) were measured at 356, 511, 662, 840, 1170, 1275 and 1330 keV photon energies for shape memory alloys materials viz. Aluminum-Nickel (AlNi), Iron- Titanium (FeTi), Zinc Copper (ZnCu), Copper-Tin (CuSn), Stainless-Steel (Fe CrNiMo), carried out by NaI (Tl) detector with a well collimated narrow beam good geometry setup. Experimentally and theoretically measured values of the mass attenuation coefficients (μ_m) for all samples listed in Table 1 at given photon energies and variation with energy (E) is displayed in Fig. 2. From Fig. 2 it is observed that the variation of m values decreases with increasing photon energy. The experimental values of μm agree with theoretical values calculated using the WinXCOM program based on the mixture rule. Measured total atomic cross section ($\sigma_{t,a}$) and total electronic cross section ($\sigma_{t,el}$) for the studied shape memory alloys are tabulated in Tables 2 and 3 respectively. The typical plots of t, a and t, el versus photon energy (E) are displayed in Figs. 3 and 4 respectively. The behavior of $\sigma_{t,a}$ and $\sigma_{t,el}$ with photon energy (E) is almost similar to that of μ_m.

The results of Z_{eff} for five samples were calculated from Eq. 6 using the values of μ_m and the same are given in Table 4. The Z_{eff} 0.533* A_{eff} relation is valid for the present case. A typical plot of Z_{eff} versus photon energy (E) is plotted for shape memory alloys samples in Fig. 5. It is clearly seen from Table 4 and Fig. 5 that the Z_{eff} values for the present samples vary and tend to be almost constant for higher gamma ray photon energy. The effective electron density (N_{eff}) is calculated using the Eq. 7 and tabulated in Table 5. The typical plot of N_{eff} versus photon energy (E) is shown in Fig. 6. It can be observed from Fig. 6 and Table 5 that the N_{eff} initially decreases and tends to be almost similar (at 1170 keV to 1330 keV) in the high photon energy range. The measured molar extinction coefficient (ε) is studied for all samples in the present case, its variation with energy (E) is displayed in Fig. 7 and represented in Table 6. It is clearly seen from Fig. 7 the ε values of the samples varied with the density of the materials such that they increased with the

increasing density for the same gamma ray energies and decreased with the increasing gamma ray energies for the materials. From all the observed and calculated data it can be illustrated that all sample shows similar variation in entire energy region. The total experimental uncertainties of the values depend on the uncertainties of I_0 (without attenuation), I (after attenuation), measurements of mass thickness values, and counting statistics. The variation of the all attenuation parameters were systematically studied in the given photon energy region.

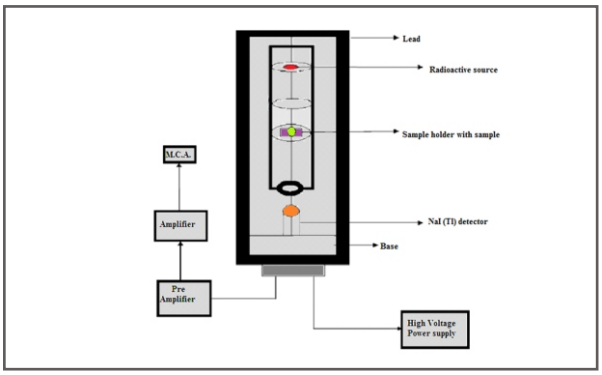

Fig. 1: Schematic set up of NaI(Tl) scintillation detector

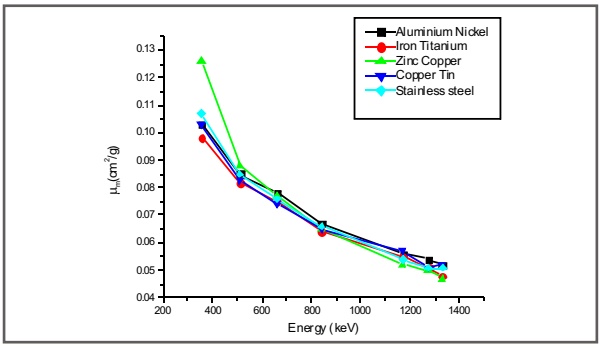

Fig. 2: The typical plots of m versus E for shape memory alloys

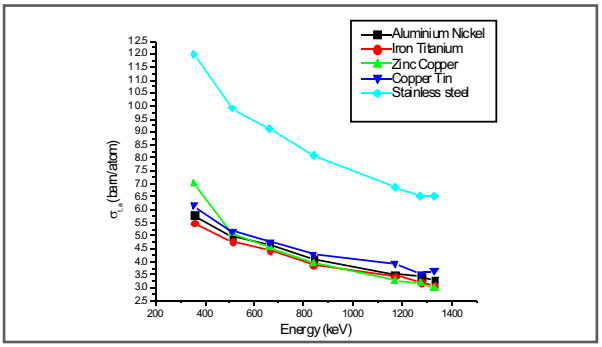

Fig. 3: The typical plots of t, a versus E for shape memory alloys

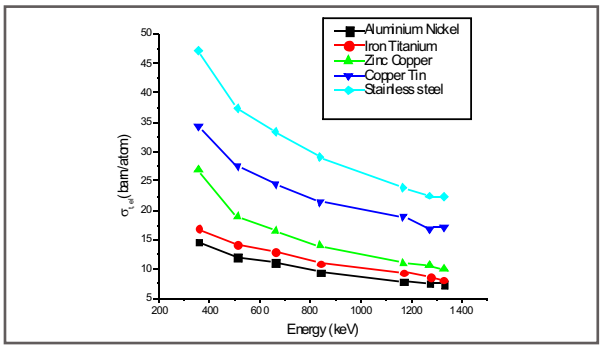

Fig. 4 : The typical plots of t, el versus E for shape memory alloys

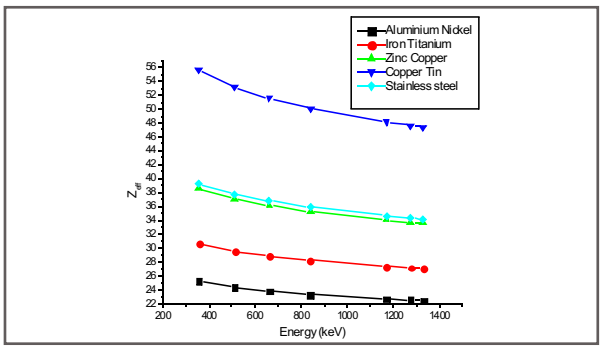

Fig. 5: The typical plots of Zeff versus E for shape memory alloys

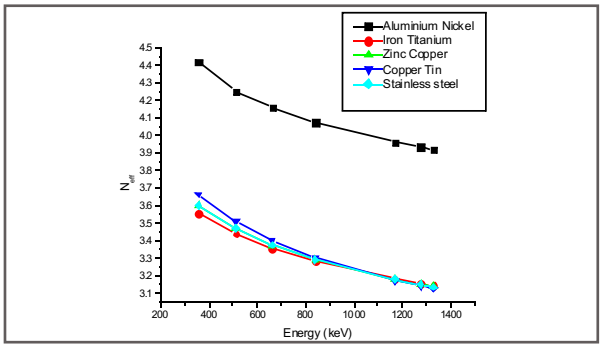

Fig. 6: The typical plots of Neff versus E for shape memory alloys

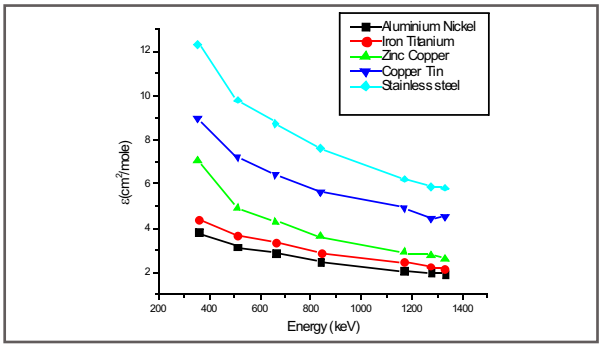

Fig. 7: The typical plots of Ɛ versus E for shape memory alloys

Table 1: Mass attenuation coefficient μm (cm^2/g) of Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron-Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	0.103	0.104	0.098	0.099	0.126	0.127	0.103	0.104	0.107	0.109
511	0.085	0.086	0.082	0.083	0.088	0.090	0.083	0.084	0.085	0.086
662	0.078	0.079	0.075	0.076	0.077	0.079	0.074	0.076	0.076	0.078
840	0.067	0.069	0.064	0.066	0.065	0.066	0.065	0.066	0.066	0.067
1170	0.056	0.058	0.055	0.056	0.052	0.054	0.057	0.056	0.054	0.056
1275	0.054	0.055	0.051	0.053	0.050	0.051	0.051	0.053	0.051	0.053
1330	0.052	0.053	0.048	0.050	0.047	0.049	0.052	0.053	0.051	0.051

Table 2: Total atomic cross-sections, $\sigma_{t,a}$ (barn/molecule) of Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron- Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	5.799	5.901	5.506	5.561	6.998	7.053	6.156	5.672	12.010	12.234
511	4.974	5.031	4.766	4.824	5.075	5.190	5.182	4.785	9.911	10.026
662	4.666	4.725	4.466	4.525	4.562	4.680	4.767	4.467	9.105	9.344
840	4.090	4.211	3.897	4.019	3.948	4.009	4.309	3.992	8.108	8.230
1170	3.516	3.641	3.455	3.518	3.269	3.395	3.932	3.525	6.869	7.122
1275	3.415	3.478	3.230	3.356	3.172	3.235	3.555	3.371	6.546	6.802
1330	3.300	3.363	3.052	3.179	2.995	3.122	3.643	3.388	6.523	6.561

Table 3: Total electronic cross-sections, $\sigma_{t,el}$ (barn/molecule) of Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron- Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	14.651	14.793	16.852	17.023	26.957	27.171	34.191	31.503	47.134	48.015
511	12.091	12.233	14.100	14.272	18.827	19.255	27.552	25.445	37.443	37.884
662	11.095	11.237	12.897	13.069	16.474	16.902	24.564	23.021	33.479	34.360
840	9.530	9.815	11.005	11.349	13.907	14.120	21.577	19.992	29.074	29.514
1170	7.966	8.250	9.457	9.629	11.125	11.553	18.921	16.963	23.787	24.668
1275	7.681	7.823	8.770	9.114	10.697	10.911	16.930	16.054	22.466	23.347
1330	7.397	7.539	8.254	8.598	10.056	10.483	17.261	16.054	22.290	22.422

Table 4: Effective atomic number, Z_{eff} of Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron- Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	25.267	25.071	30.608	30.610	38.521	38.523	55.540	55.543	39.245	39.247
511	24.309	24.313	29.587	29.588	37.096	37.099	53.170	53.174	37.781	37.784
662	23.781	23.784	28.875	28.878	36.109	36.111	51.534	51.539	36.769	36.771
840	23.303	23.307	28.237	28.239	35.225	35.226	50.078	50.080	35.859	35.862
1170	22.656	22.660	27.373	27.374	34.030	34.031	48.116	48.119	34.631	34.635
1275	22.493	22.495	27.151	27.154	33.725	33.727	47.620	47.622	34.321	34.324
1330	22.412	22.415	27.044	27.046	33.575	33.579	47.378	47.381	34.170	34.172

Table 5: Effective electron densities, $N_{eff}(10^{24})$ Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron- Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	4.420	3.525	3.560	3.560	3.601	3.601	3.667	3.667	3.604	3.605
511	4.253	3.418	3.441	3.441	3.468	3.468	3.511	3.511	3.470	3.470
662	4.160	3.344	3.358	3.359	3.376	3.376	3.403	3.403	3.377	3.377
840	4.077	3.277	3.284	3.284	3.293	3.293	3.306	3.307	3.293	3.294
1170	3.963	3.186	3.184	3.184	3.181	3.181	3.177	3.177	3.181	3.181
1275	3.935	3.163	3.158	3.158	3.153	3.153	3.144	3.144	3.152	3.152
1330	3.921	3.152	3.145	3.146	3.139	3.139	3.128	3.128	3.138	3.138

Table 6: Molar extinction coefficients (ε) of Shape Memory Alloy's

Energy	Aluminum-Nickel		Iron- Titanium		Zinc Copper		Copper-Tin		Stainless-Steel	
	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo	Exp	Theo
356	3.834	3.871	4.409	4.454	7.054	7.110	8.946	8.243	12.333	12.564
511	3.164	3.201	3.689	3.734	4.926	5.038	7.209	6.658	9.797	9.913
662	2.903	2.940	3.375	3.420	4.311	4.423	6.428	6.024	8.760	8.991
840	2.494	2.568	2.880	2.970	3.639	3.695	5.646	5.231	7.607	7.723
1170	2.084	2.159	2.475	2.520	2.911	3.023	4.951	4.439	6.224	6.455
1275	2.010	2.047	2.295	2.385	2.799	2.855	4.430	4.201	5.878	6.109
1330	1.935	1.973	2.160	2.250	2.631	2.743	4.517	4.201	5.832	5.867

CONCLUSION

In this research μ_m were investigated to get sufficient information about mass attenuation coefficients (μ_m), total atomic cross section ($\sigma_{t,a}$), total electronic cross section ($\sigma_{t,el}$), effective atomic numbers (Z_{eff}), and molar extinction coefficient (ε) for shape memory alloys materials and it has been observed that the present data on m values and other parameters are very useful in biomedical, medical and biological, sensor/actuator, coupling and other applications. In this paper, we reported that the experimental data on (μ_m), ($\sigma_{t,a}$), ($\sigma_{t,el}$), (Z_{eff}), and (ε) of shape memory alloys materials at different photon energy range. Mass attenuation coefficient and other parameters of all samples have been calculated at 356 keV to 1330 keV photon energies. This study concludes that any compound material depends on its chemical composition, density, and concentration of the elements that it contains

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