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INVESTIGATION OF NUCLEAR RADIATION INTERACTION PARAMETERS OF NICKEL-BASED SHAPE MEMORY ALLOYS

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Abstract- In this study, the fast neutron removal cross section (FNRCS), mass attenuation coefficient (μ/ρ), half-value thickness (HVL), tenth value thickness (TVL), mean free path (λ), total electronic cross section (σte), total molecular cross section (σtm), effective atomic number (Zeff) and the effective electronic density (Neff) the values were calculated for nickel-based shape memory alloy at different energy. Important another nuclear attenuation parameter relevant to shielding i.e. the fast neutron removal cross section (FNRCS) was be calculated for alloys. NiTiPt possesses the best FNRCS (= 0.143) among the present studied alloys.

Keywords: Shape memory alloys, half-value thickness, fast neutron removal cross section.

1. INTRODUCTION

The unique feature of nuclear power plants, as distinct from other power-generating facilities, is the presence of large amounts of radioactive materials, primarily the fission products [1].

Nowadays, potentially disastrous events, such as accidental release of radioactive materials from nuclear plant installations have become a major humanity concern. With the increasing use of ionize radiation in medical, industrial, agricultural, nuclear power generation sectors, etc. in the last few decades, development of studies that offer adequate protection of living things beings from radiation exposures has become an important issue. Among the main rules of thumb for radiation protection, shielding is particularly important in terms of effectiveness. Hence, it is of interest to investigate the radiation shielding capability of various materials.

The main characteristic of shape memory alloys is that they can have two different crystal orders at the limit values of a critical temperature. Shape memory alloys (SMAs) are elements that are capable of phase transformation by switching to martensite structure at lower level temperature and austenite structure at higher level temperature of this critical temperature [2]. NiTi alloys are materials of commercial value in the industry in (SMAs). Ni-based alloys are alloys with a shape change value of 8%. This value is quite good compared to other alloys [3]. In the literature, it has been observed that theoretical data on the interaction parameters of shape memory alloys against radiation does not find much place. The main purpose of this work is to use the WinXCOM and Phy-X/PSD data programs various energy is also to calculate mass absorption coefficients and other absorbance parameters. The software can generate data on shielding parameters in the continuous energy region (1 keV-100 GeV) [4]. As radiation penetrates matter and interacts with atoms and electrons, some changes in the material structure occur. As a result of the interaction, some of the energy of the radiation is absorbed according to the material property. It is important to investigate alternative substances in the armoring event. Calculation of absorption parameters of substances of different structures used as radiation armor gives preliminary information about whether these substances can be a protective shield against radiation [5].

2. MATERIAL AND METHOD

In the literature, it has been observed that theoretical data on the interaction parameters of shape memory alloys against radiation does not find much place. The main purpose of this work is to use the WinXCOM and Phy-X/PSD programs especially 5.6, 6.1, 8, 11.2, 25, 59.543 and 75 keV energy is also to calculate mass attenuation coefficients and other absorbance parameters. Mass attenuation coefficient (μ/ρ) is the characteristic absorbance property of elements independent of characteristic properties. The mass attenuation coefficient, defined as a physical quantity that changes depending on energy, was calculated using Equation (1);

$$MAC = \left(\frac{\mu}{\rho}\right)_{Alloy} = \sum_{i} \omega i \left(\frac{\mu}{\rho}\right)_{i} \quad ; \ \omega_i = \frac{a_i A_i}{\sum a_i A_i} \tag{1}$$

In Equation (1), ρ is the density, ω_i is fractional weight, (μ/ρ) is the mass attenuation coefficient of the element.

The half-value layer (HVL) of the absorbent Ni-based alloy refers to the absorbent thickness required to halve the photon intensity coming out of the source and into the alloy, and the one-tenth (1/10) value layer (TVL) refers to the alloy thickness required to reduce the high-energy photon intensity interacting with the alloy to 1/10. HVL, TVL and Mfp (λ) values were calculated using equations 2,3 and 4 [6], [7].

$$HVL = \frac{In2}{LAC_{alloy}} = \frac{In2}{\mu_{alloy}} = \frac{0.6931}{\mu_{alloy}} \tag{2}$$

$$TVL = \frac{In10}{LAC_{alloy}} = \frac{In10}{\mu_{alloy}} = \frac{2.3025}{\mu_{alloy}} \tag{3}$$

The 1 MFP parameter is calculated using the mean free path Equation (4).

$$MFP = \frac{1}{LAC_{alloy}} = \frac{1}{\mu_{alloy}} \tag{4}$$

Mass attenuation coefficients are calculated using the mixture rule for alloys. The total molecular effect cross-section (σtm) for alloy materials was calculated using Equation (5); [8].

$$\sigma_{tm} = \frac{1}{N_A}\left(\frac{\mu}{\rho}\right)_C \sum_i n_i \; A_i \tag{5}$$

The total electronic cross-section (σte) of the alloy material was calculated using the formula (6); [8].

$$\sigma_{te} = \frac{1}{N_A}\sum_i f_i \frac{A_i}{Z_i}\left(\frac{\mu}{\rho}\right)_i ; \quad f_i = \left(\frac{n_i}{\sum_i n_i}\right) \tag{6}$$

The active atomic number (Zeff) was calculated using the formula (7); [9].

$$Z_{eff} = \frac{\sigma_{ta}}{\sigma_{te}} \tag{7}$$

The effective electron density (Neff) was calculated using the Formula (8) [10].

$$N_{eff} = \frac{N_A \; n_{tot} Z_{eff}}{\sum_i n_i \; A_i} \tag{8}$$

In the formula (8), n_{tot} is the total number of atoms, N_A Avogadro number, A_i atomic weight, n_i ratio of atoms forming an alloy, Z_{eff} is the active atomic number.

Furthermore, the ability of the alloys to attenuate fast neutron removal is evaluated in this manuscript. The Fast Neutron Removal Cross Section (FNRCS) is estimated through following Eq (9) [11].

$$FNRCS = \sum_i \rho_i \left(\frac{FNRCS}{\rho}\right)_i \tag{9}$$

$$\rho_i = \omega_i \, \rho$$

Where *ωi* and *ρi* are the weight fraction and partial density of ith constituent element, respectively. The value of *FNRCS/ρ* for each element is as follow as Eq. (10) [11].

$$\frac{FNRCS}{\rho} = \begin{cases} 0.190\, Z^{-0.743} & Z \leq 8 \\ 0.125\, Z^{-0.565} & Z > 8 \end{cases} \tag{10}$$

RESULTS

In this study, absorption parameters of Ni-based shape memory alloys μ/ρ, HVL, TVL, λ, Zeff, Neff, σtm, σte 5.9, 6.1, 8, 11.2, 25, 59.543, 75 keV photon energies were calculated and listed in Table 1-3.

Table-1 Mass absorption coefficient μ/ρ (cm^2/gr) values of Ni-based form memory alloys

Ni-based Shape Memory Alloys		5.9 keV	6.1 keV	8 keV	11.2 keV	25 keV	59.543 keV	75 keV
S1	0.50 Ni-0.50Ti	284.8	257.7	125.9	118.3	12.83	1.161	0.658
S2	0.50 Ni- 0.40 Ti- 0.10 Pd	284.3	257.8	125.9	118.4	17.51	1.634	0.906
S3	0.50 Ni- 0.40 Ti- 0.10 Pt	281.8	255.7	125.6	118.7	16.23	1.526	0.857
S4	0.50 Ni- 0.35 Ti- 0.15Cu	234.6	212.6	103.5	130.6	14.3	1.288	0.722
S5	0.50 Ni- 0.35 Ti- 0.15Nb	266.2	241.5	117.6	115	18.07	1.662	0.918
S6	Ni	114.1	104.1	49.52	155.7	17.29	1.542	0.853

Table-2 Effective atomic number Zeff values of Ni-based form memory alloys

Ni-based Shape Memory Alloys	5.9 keV	6.1 keV	8 keV	11.2 keV	25 keV	59.543 keV	75 keV
S1	27.630	27.629	27.619	28.176	27.658	27.643	27.628
S2	24.709	24.711	24.695	25.082	25.092	25.080	25.068
S3	27.150	27.143	27.140	27.713	27.122	27.067	27.066
S4	30.823	30.811	30.786	33.022	30.648	30.493	30.461
S5	28.015	25.823	27.983	26.106	26.093	26.099	26.089
S6	28	28	28	28	28	28	28

Table-3 Effective electron density $N_{eff}x10^{23}$ (electron/gram) values of Ni-based SMAs

Ni-based Shape Memory Alloys	5.9 keV	6.1 keV	8 keV	11.2 keV	25 keV	59.543 keV	75 keV
S1	2.764	2.764	2.763	2.819	2.767	2.766	2.764
S2	2.785	2.785	2.783	2.827	2.828	2.827	2.825
S3	2.758	2.757	2.757	2.815	2.755	2.749	2.749
S4	2.723	2.722	2.720	2.918	2.708	2.694	2.691
S5	3.024	2.788	3.021	2.818	2.817	2.817	2.816
S6	2.859	2.859	2.859	2.859	2.859	2.859	2.856

Table 4. Fast neutron removal cross section (1/cm) of the given Ni based SMAs

Ni-based Shape Memory Alloys	FNRCS
S1	0.132
S2	0.139
S3	0.143
S4	0.142
S5	0.136
S6	0.169

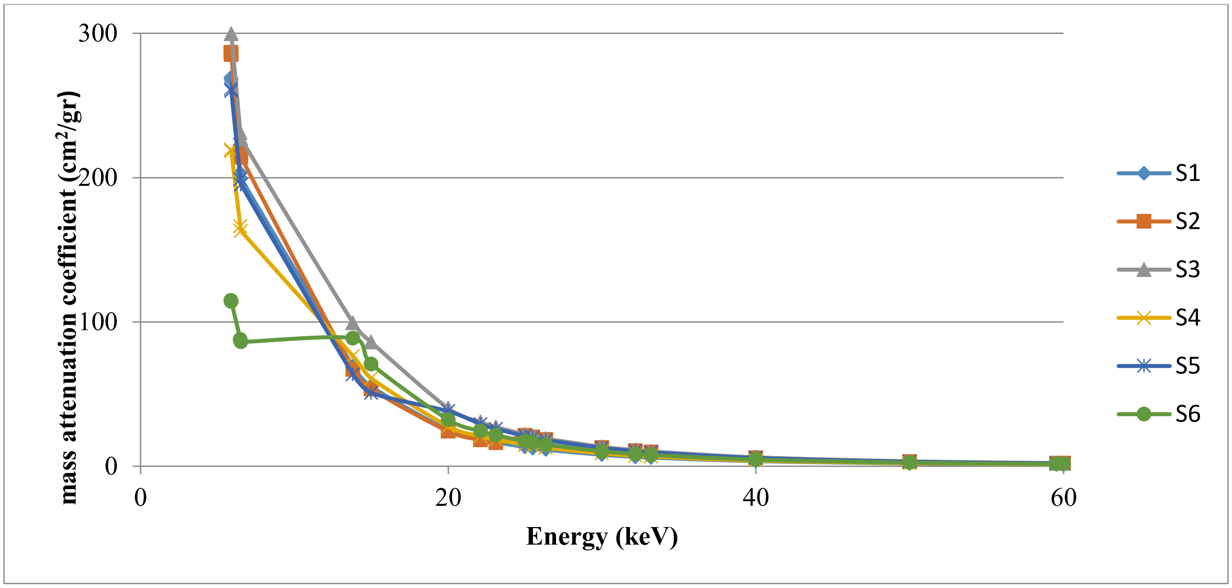

Fig. 1 Change in mass absorption coefficients of Ni-based SMA relative to energy

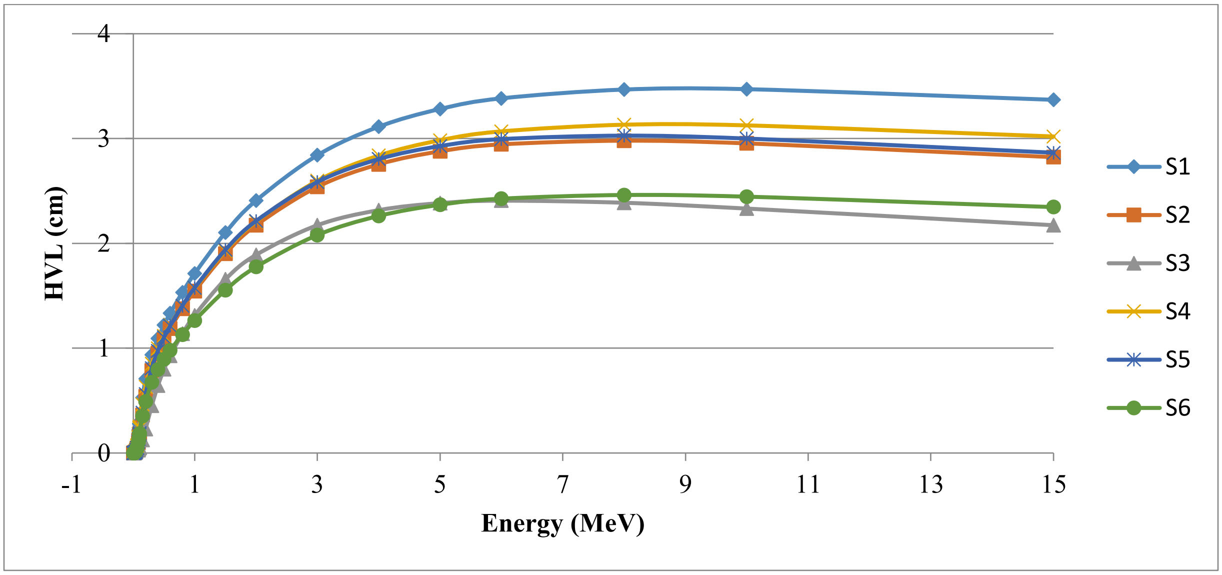

Fig. Half-value layer (HVL) change of Ni-based SMA according to energy

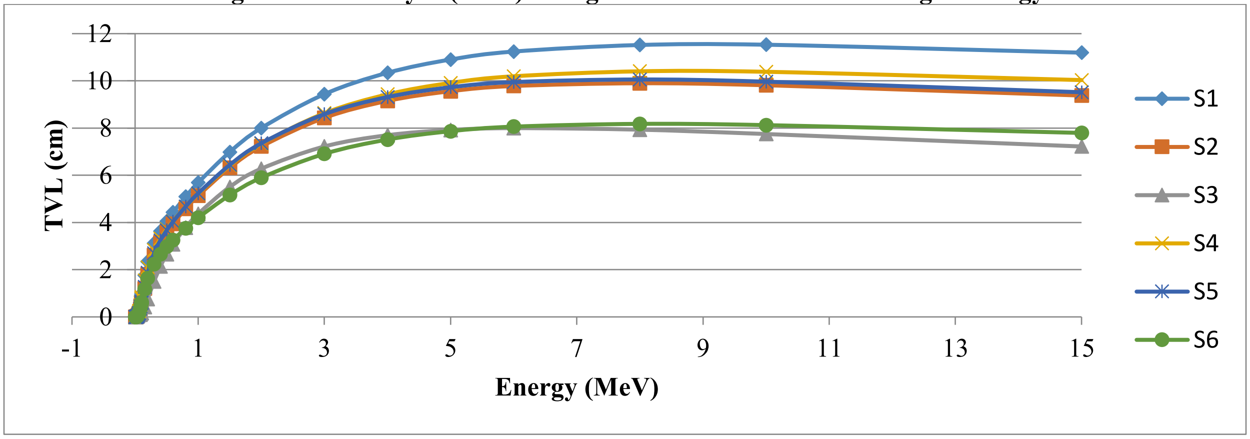

Fig. 3 Change of Ni-based SMA by one-tenth value layer (TVL) relative to energy

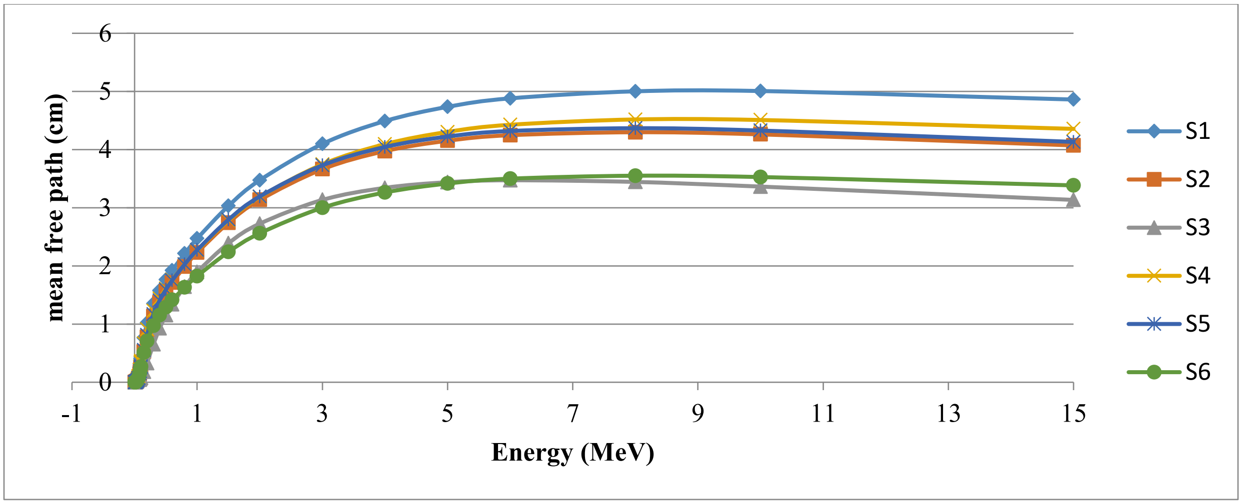

Fig. 4 MFP change of Ni-based SMA by energy

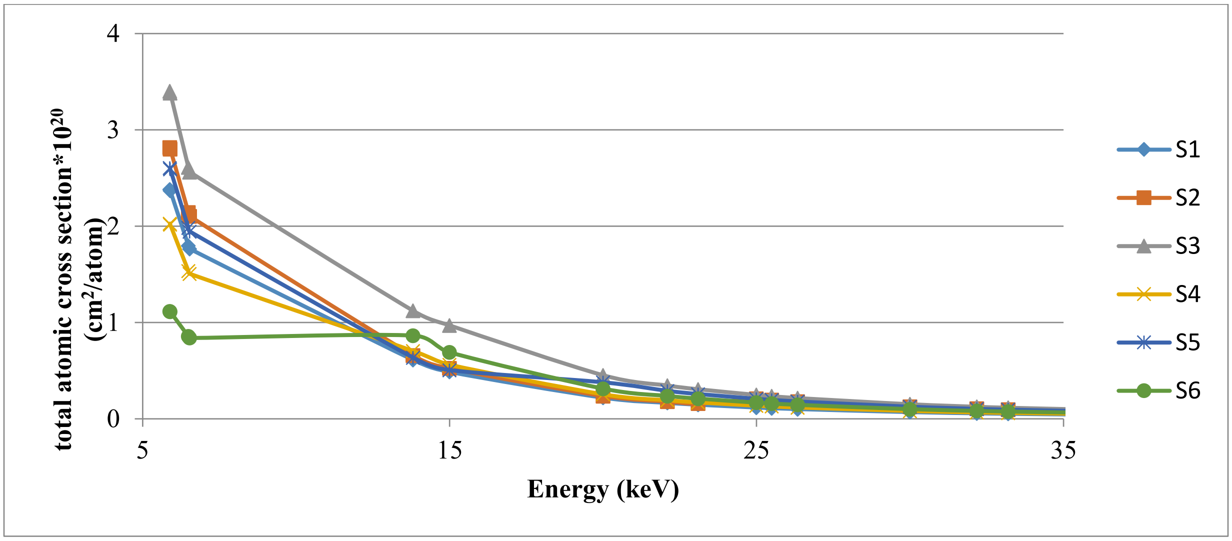

Fig. 5 Change graph of total molecular effect cross section of Ni-based SMA by energy

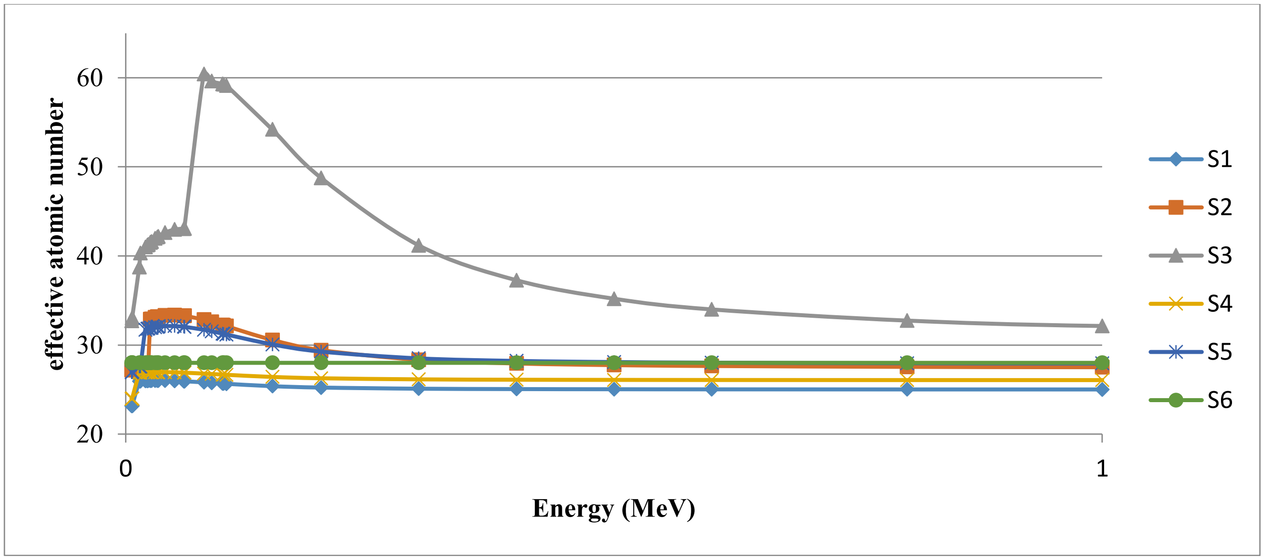

Fig. 6 Change graph of effective atomic number of Ni-based SMA at 1 MeV energy

As the Ti ratio increases in alloys, it has been observed that the absorption property of the material increases, but also that there are not very large changes in cases where one of the elements Pd, Pt, Cu, Nb is added to the NiTi alloy by 10-15%. In addition, it is observed that the amount of Ti causes a decrease in the values of the alloy's mass absorption coefficient. In this study, mass attenuation data of 50%Ni-50%Ti alloys were found to be high when compared to the absorption parameters of NiTi, NiTiPd, NiTiPt, NiTiCu, NiTiNb alloys to get sufficient information about μ/ρ, HVL, TVL and λ of Ni-based shape memory alloys. From Table 1, it was observed that the mass absorption coefficients of Ni-based SMA alloys decrease with increased energy. Because the photoelectric event is dominant in the low energy region, absorption coefficients have been observed to decrease with increasing energy. 50% Ni-40% Mo-10% Pt alloy was found to be the alloy with the highest effective atomic number value. Pure Ni element with atomic number 28 was found to cause an increase in the effective atomic number by adding nickel by 50% in the NiTi alloy (interaction with energy and mopping up high atomic number Pt). At the same time, a small decrease in Zeff values was observed in alloys with an increase in energy. By analyzing the results of molecular and electronic cross-sections for pure Ni metals and Ni-based SMA, increased photon energy reduces the likelihood that the photon will interact with atoms and electrons.

CONCLUSION

The current study was conducted to predict the reactions of alloys to high-energy photons when Ni-based SMA, which are widely used in future studies, are used in radiation environments so that they can be used as a reference to researchers. Alloys that show a shape memory effect find an intensive use in the technology of our age. Figure memory alloy is used in environments where the material will interact with radiation, such as nuclear facilities, hospital radiation applications, it was thought that the reaction of the material should be known in advance. It is believed that the alloy obtained by adding titanium to the element nickel in half can find use as a good protective material against high energies. In this study, it was observed how the amount of Ti changes the alloy's mass absorption coefficient and other absorption parameters.

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