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Gamma, X-ray and neutron shielding parameters for the Al-based glassy alloys

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HIGHLIGHTS

- X-ray, gamma and neutron shielding parameters for Al-based glassy alloys.
- $Al_{60}Y_{33}Ni_5Co_1Fe_{0.5}Pd_{0.5}$ is good for shielding the X-ray/gamma radiation.
- $Al_{86}Y_7Ni_5Co_1Fe_{0.5}Pd_{0.5}$ is good for shielding neutrons.

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ABSTRACT

The X-ray and gamma radiation shielding parameters (mass attenuation coefficient, mean free path, half value layer, tenth value layer, effective atomic numbers, electron density, exposure buildup factors, relative dose, dose rate and specific gamma ray constant) have been studied for the Al-based glassy alloys $Al_{86}Y_7Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{85}Y_8Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{84}Y_9Ni_4Co_{1.5}Fe_{0.5}Pd_1$, $Al_{80}Y_{13}Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{70}Y_{23}Ni_5Co_1Fe_{0.5}Pd_{0.5}$ and $Al_{60}Y_{33}Ni_5Co_1Fe_{0.5}Pd_{0.5}$. For the same alloys, the neutron shielding parameters (coherent neutron scattering length, incoherent neutron scattering lengths, coherent neutron scattering cross section, incoherent neutron scattering cross sections, total neutron scattering cross section and neutron absorption cross sections) have also been explored. $Al_{60}Y_{33}Ni_5Co_1Fe_{0.5}Pd_{0.5}$ was found to be a good shielding material for the X-ray/gamma radiation, while $Al_{86}Y_7Ni_5Co_1Fe_{0.5}Pd_{0.5}$ is a good shielding material for neutrons.

1. Introduction

Alloys with an amorphous structure have great potential for industrial applications due to their interesting chemical, mechanical and magnetic properties (Milanez et al., 2017). Thus, Afkham et al. (2017) studied the tensile properties of the Al-Cr-Co-Fe-Cu-Ni glassy alloys. Hans et al. (2017) studied the thermal stability and crystallization of the glassy alloys of the composition of Al-Y-Ni-Co-Fe-Pd. Peng et al. Peng et al. (2015) studied the temperature- and composition-dependent dynamic properties of the Al-Au alloys. Breitzke et al. (2004) studied the structure of the metallic glass alloy of Zr-Cu-Al-Ni-Ti. Sarpreet Kaur et al. (2016) computed shielding parameters of the Pb-Sn binary alloys in a wide energy range of 1 keV to −100 GeV. Li et al. (2017) studied the radiation shielding capability of a structural polymer composite containing erbium oxide. Aluminium alloys are the primary material for the structural parts of aircraft (Dursun and Soutis, 2014). Cui et al. (2011) investigated the effect of yttrium on the microstructure and mechanical properties of the Mg–Li–Al–Zn alloy. Singh and Badiger (2014) studied the photon and neutron shielding properties of some alloy materials. Chen et al. (2015) studied the shielding effectiveness and mechanical properties of the Mg–Zn–Cu–Zr alloys.

In our previous work (Manjunatha, 2015, 2016; Seenappa et al., 2017; Manjunatha et al., 2017a, 2016; Rudraswamy et al., 2010), we measured the X-ray and gamma interaction parameters for some compounds of dosimetric interest. We also reported results of theoretical calculations of the X-ray and gamma interaction parameters of biological samples (Manjunatha and Rudraswamy, 2013, 2011a; Suresh et al., 2008; Manjunatha, 2014). In our previous paper (Manjunatha

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et al., 2012), we reported shielding parameters for the beta and bremsstrahlung radiation in concretes. In a previous work, we also estimated the energy exposure buildup factors using the GP fitting method (Manjunatha and Rudraswamy, 2012a, 2011b, 2012b).

In the present work, we studied the X-ray and gamma radiation shielding parameters, such as the mass attenuation coefficient, mean free path, half value layer (HVL), tenth value layer (TVL), effective atomic number, electron density, exposure buildup factors, relative dose, dose rate and specific gamma ray constant for a variety of Al-based glassy alloys, such as $Al_{86}Y_7Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{85}Y_8Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{84}Y_9Ni_4Co_{1.5}Fe_{0.5}Pd_1$, $Al_{80}Y_{13}Ni_5Co_1Fe_{0.5}Pd_{0.5}$, $Al_{70}Y_{23}Ni_5Co_1Fe_{0.5}Pd_{0.5}$ and $Al_{60}Y_{33}Ni_5Co_1Fe_{0.5}Pd_{0.5}$. We also studied neutron shielding properties, such as the coherent neutron scattering length, incoherent neutron scattering lengths, coherent neutron scattering cross section, incoherent neutron scattering cross sections, total neutron scattering cross section and neutron absorption cross sections for the same Al-based glassy alloys.

2. Theory

2.1. Gamma/X-ray interaction parameters

In this work, the mass attenuation coefficients (MACs) and photon interaction cross sections in the energy range from 1 keV to 100 GeV were obtained with WinXCom (Gerward et al., 2004) and its elemental composition component. The total linear attenuation coefficient (μ) can be evaluated by multiplying the density of a compound by its mass attenuation coefficients:

$$\mu = \left(\frac{\mu}{\rho}\right)_c \times \rho. \tag{1}$$

The total linear attenuation coefficient (μ) was used in calculations of the half value layer (HVL). HVL is the thickness of an interacting medium that reduces the radiation level by a factor of 2 and can be calculated by the following equation:

$$HVL = \frac{ln2}{\mu} = \frac{0.693}{\mu}. \tag{2}$$

The total linear attenuation coefficient (μ) was also used to calculate the tenth value layer (TVL), which is the thickness of an interacting medium necessary for attenuating radiation beam intensity to 10% of its initial value. It was computed using the equation

$$TVL = \frac{ln10}{\mu} = \frac{2.303}{\mu}. \tag{3}$$

The average distance between two successive interactions is called the relaxation length (λ). It is also called the photon mean free path, which is determined by the equation

$$\lambda = \frac{\int_0^\infty x\exp(-\mu x)dx}{\int_0^\infty \exp(-\mu x)dx} = \frac{1}{\mu}. \tag{4}$$

The gamma interaction parameters, such as the linear attenuation coefficient μ (cm^{-1}), HVL (cm), TVL (cm) and the mean free path λ, were calculated using Eqs. (1)–(4) above. The total molecular cross section σ_m (millibarn) was computed from the values of the mass attenuation coefficients [$(\mu/\rho)_c$] using the following equation:

$$\sigma_m(E) = \left(\frac{1}{N}\right)\left(\frac{\mu}{\rho}(E)\right)_c \sum_i n_i A_i. \tag{5}$$

Here, n_i is the number of atoms of the i^{th} element in a given molecule, $(\mu/\rho)_c$ is the mass attenuation coefficient for the compound, N is the Avogadro's number and A_i is the atomic weight of the element i. The effective (average) atomic cross section for a particular atom in a compound σ_a (millibarn) was estimated using the equation

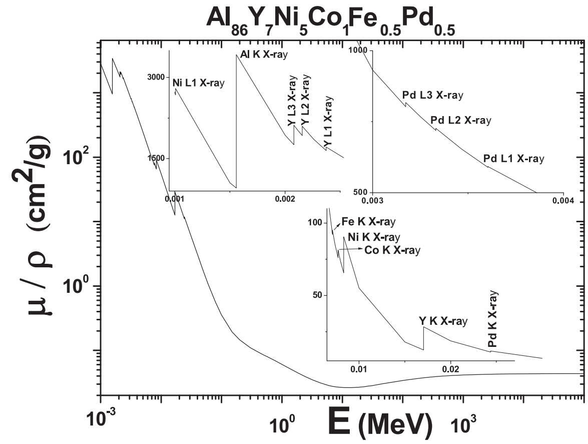

Fig. 1. Variations of the total mass attenuation coefficient with the photon energy for $Al_{86}Y_7Ni_5Co_1Fe_{0.5}Pd_{0.5}$.

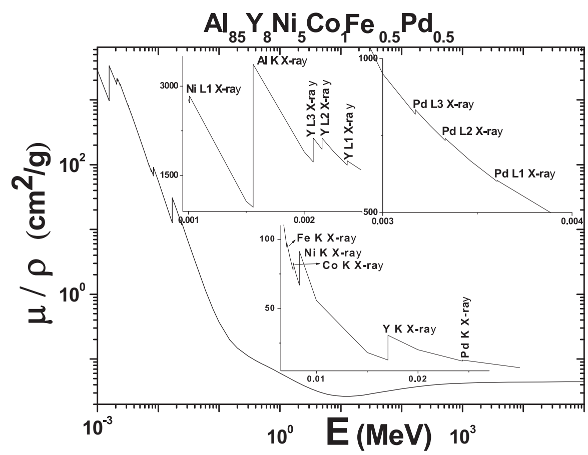

Fig. 2. Variations of the total mass attenuation coefficient with the photon energy for $Al_{85}Y_8Ni_5Co_1Fe_{0.5}Pd_{0.5}$.

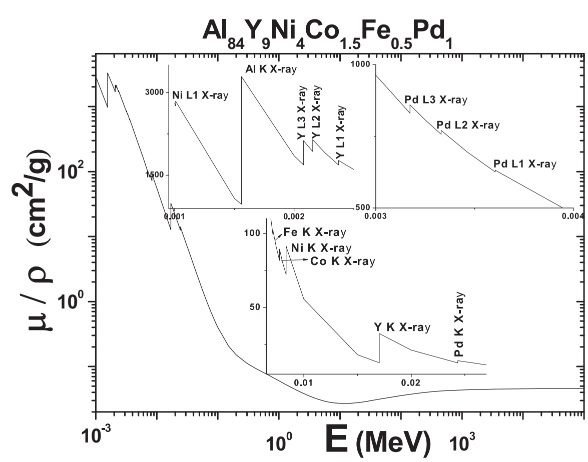

Fig. 3. Variations of the total mass attenuation coefficient with the photon energy for $Al_{84}Y_9Ni_4Co_{1.5}Fe_{0.5}Pd_1$.

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} = \frac{\left(\frac{1}{N}\right)\left(\frac{\mu}{\rho}(E)\right)_c \sum_i n_i A_i}{\sum_i n_i}. \tag{6}$$

The effective electronic cross section σ_e (millibarn) was computed

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