The Interaction Radiation and Exposure Buildup Factors Properties of AM60 and AZ91 Alloys

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Abstract

In this research to study the total and partial interaction, radiation shielding and buildup factors properties of AM60 and AZ91 alloys. Radiation shielding effectiveness of alloys were computed by determine mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}), effective electron density (N_{el}) and mean free path (MFP) at photon energy ranging 10^{-3}–10^{5} MeV using WinXCom software program. Buildup factors (BFs) were estimated by Geometric Progression (G-P) fitting theory at energy ranging 15 keV-15 MeV up to 40 mfp deep penetration. The results from simulation technique indicated that, the radiation interaction with matter values can be discussed on fundamental of partial interaction processes as photoelectric absorption effect, Compton scattering and pair production which main processes at low, intermediate and high energies, respectively. In addition, AZ91 alloy was found excellent radiation shielding and can be developed for radiation shielding medium.

Keywords: Alloys, Radiation shielding, Buildup factors, Simulation technique

Introduction

At present day, radiation isotope was used in many industrials. Whereas, these sources are very dangerous for human health, environment and laboratory equipment which the dangerous of radiation is varied by shielding, source distancing and time. So, protection radiation is important necessary to solve these problems. The most effective theory for reduce of radiation is protection. The against radiation parameters like mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}), effective electron density (N_{el}), mean free path (MFP) and buildup factors (BFs) are commonly and important quantity in sector of radiation physics (Chanthima & Kaewkhao, 2013; Kaur & Singh, 2014; Aygün, 2020; Sayyed, Elmahroug, Elbashir, & Issa, 2017; Sayyed & Elhouichet, 2017).

Alloys, once of medium was used in many applications such as nuclear reactors, petrochemical sectors and irradiation (Singh & Badiger, 2014; Vishwanadh et al., 2012). Magnesium is favored and widely used to magnesium alloys due to lightweight whereas these magnesium alloys have limited conditions such as poor weldability, ductility and low absolute strength. So, magnesium alloys had been mixed some elements to solve their problems and can been met in magnesium alloys series such as AM60 and AZ91. AM60 is Mg + Al + Mn alloy and AZ91 is Mg + Al + Zn alloys, were used for many fields of industrials due to AM60 is good thermal stability, suitable strength and ductility and AZ91 alloys is excellent corrosion resistance, good cast ability and relatively high strength (Sameer & Birru, 2019; Barati, Latifi, Moayeri far, Mosallanejad, & Saboori, 2019; Fujisawa & Yonezu, 2014; Xu et al., 2020).

In this context was studied and reported theoretical values of total and partial mass attenuation coefficient (μ_m), effective atomic numbers (Z_{eff}), effective electron densities (N_{el}) and mean free path (MFP) of AM60 and AZ91 alloy using WinXCom software program at energies ranging 10^{-3}–10^{5} MeV which these energies ranging covered the important radiation interaction: photoelectric absorption effect, Compton scattering and pair production, also buildup factors (BFs) have been reported at 15 keV–15 MeV.

Methods and Materials

The mass attenuation coefficient (μ_m) values of mixture or compound are parameter which important for photon interaction. The theoretical of this value has been estimated by mixture rule using WinXCom software which widely used in the field of radiation shielding materials and computed from Eq. (1) (Kaur, Singh & Anand, 2015; Yılmaz, Boydaş & Cömert, 2016),

$$\mu_m = \frac{\mu}{\rho} \quad (1)$$

here μ and ρ are linear attenuation coefficients and density of medium, respectively.

The effective atomic number (Z_{eff}) for alloy include many elements cannot show with one number. Z_{eff} can computed from divide total atomic cross section ($\sigma_{t,a}$) by total electronic cross section ($\sigma_{t,el}$) as computed below (Agar et al., 2019; Limkitjaroenporn, Kaewkhao, Limsuwan & Chewpraditkul, 2011; Dong et al., 2017; Kumar, 2017; Issa, Kumar, Sayyed, & Dong, Elmahroug, 2018),

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad (2)$$

$$\sigma_{t,a} = \frac{\mu_m}{N_A \sum_i (w_i / A_i)} \quad (3)$$

$$\sigma_{t,el} = \frac{1}{N_A} \sum_i \frac{f_i A_i}{Z_i} (\mu_m)_i \quad (4)$$

The electron density (N_{el}) is among of electrons per total mass unit, can be computed by Eq. (5) (Sayyed & Elhouichet, 2017; Tekin et al., 2019; Kumar, 2017; Issa et al., 2018),

$$N_{el} = \frac{\mu_m}{\sigma_{t,el}} \quad (5)$$

Mean free path (MFP) investigates average distance passed though by photon between two consecutive collisions or scatterings in medium and compute from Eq. (6) (Kumar, 2017; Kaçal, Akman, Sayyed & Akman, 2019; Dong et al., 2019),

$$MFP = \frac{1}{\mu} \quad (6)$$

Finally, energy absorption and exposure buildup factor (EABF and EBF) of AM60 and AZ91 alloys were estimated using G-P fitting theory which taken data from ANSI/ANS 6.4.3 (Kaur, Singh, & Singh, 2018; Singh, Badiger, Chanthima & Kaewkhao, 2014) and composition of alloys were exhibited in Table 1.

Table 1 Composition of alloy %wt.

Sample	Elements (%wt)						
	Al	**Mn**	**Si**	**Cu**	**Zn**	**Ni**	**Mg**
AM60	6.5	0.16	0.5	0.35	0.22	0.03	92.24
AZ91	9.7	0.13	0.5	0.1	1	0.03	88.54

Results and Discussion

1. Total interaction and mass attenuation coefficient (μ_m)

The interaction of photon with medium is Coherent scattering, incoherent (Compton) scattering, photoelectric absorption effect, nuclear and electron pair production. These partial interactions can discuss by total mass attenuation coefficient with photon energies and the results from simulation can exhibited in Figure 1 which a) AM60 and b) AZ91. These figures presented that at low energies ranging ($E < 0.04$ MeV), intermediate energies ranging ($0.04 < E < 3$ MeV), and high energies ranging ($E > 3$ MeV), are three photon energies ranging of interaction processes. Figure 2 presents μ_m values of AM60 and AZ91 alloys. As presented in Figure 2, μ_m values of alloys decrease rapidly, from 9.92×10^{2} to 5.26×10^{-1} cm^2g^{-1} and 9.79×10^{2} to 5.55×10^{-1} cm^2g^{-1} for AM60 and AZ91, respectively, as energies increases until 0.04 MeV. In these energies ranging, graphs are not continuous because of K and L absorption edges of elements as presented in Table 2. This mechanism of μ_m with energy due to photoelectric absorption effect cross-section which relative to $E^{-3.5}$ (Singh & Badiger, 2014; Tekin et al., 2019). At energies ranging $0.04 < E < 3$ MeV, μ_m for AM60 and AZ91 alloys adjust slowly, from 0.526 to 0.036 cm^2g^{-1} and 0.555 to 0.036 cm^2g^{-1} for AM60 and AZ91, respectively as presented in Figure 2. This due to Compton scattering is main behavior which cross-section process is relative to E^{-1} and linearly adjusts with Z number (Issa et al., 2017). For energies increasing from 3 MeV-10^{5} MeV, μ_m values increase and nearly constant. This due to pair production process is main behavior. The results present that AZ91 alloy has higher μ_m value than AM60.

Table 2 Absorption edges (keV) for elements.

Absorption edges (keV)	Elements						
	Mg	**Al**	**Si**	**Mn**	**Ni**	**Cu**	**Zn**
K	1.31	1.56	1.84	6.54	8.33	8.98	9.66
L1					1.01	1.10	1.19
L2							1.04
L3							1.02

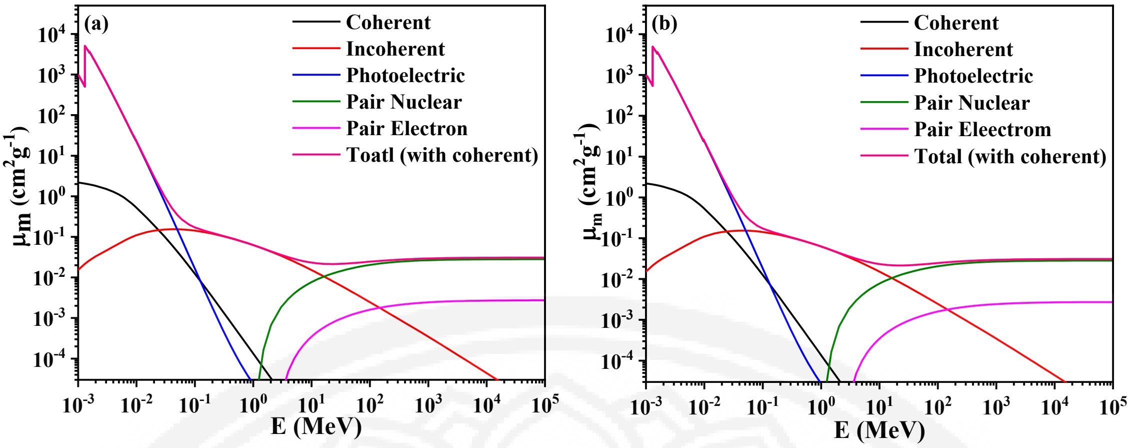

Figure 1 μ_m of total and partial for a) AM60 and b) AZ91 VS energy

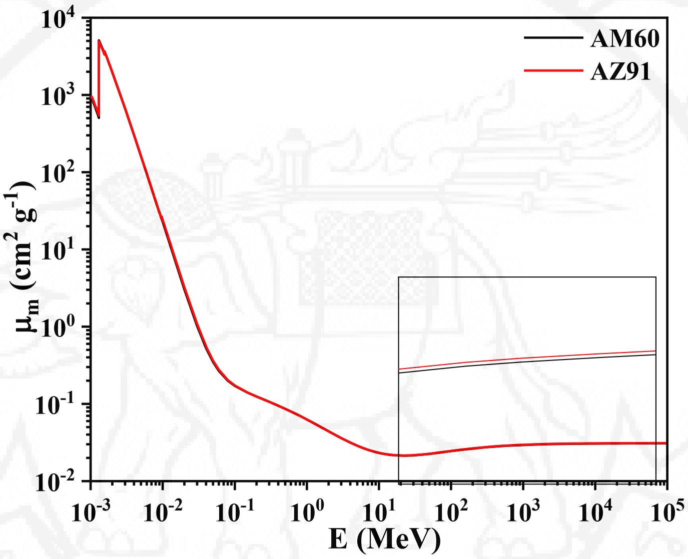

Figure 2 μ_m VS energies for alloys at 10^{-3}–10^{5} MeV

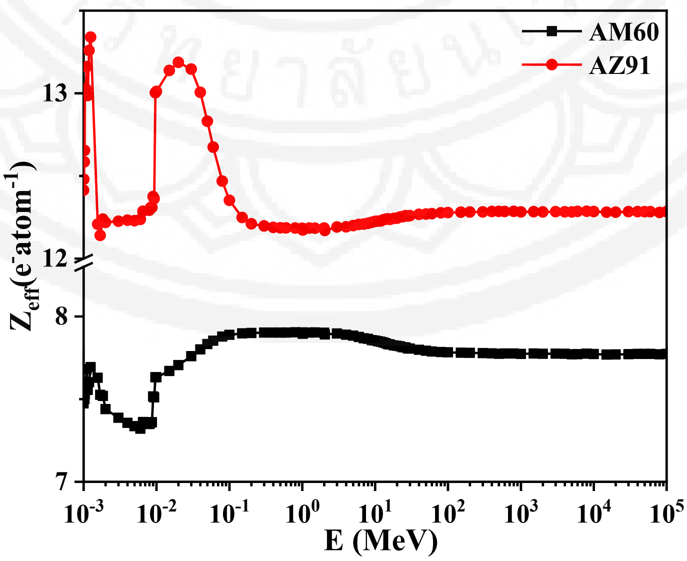

Figure 3 Z_{eff} VS energies for alloys at 10^{-3}–10^{5} MeV

2. Effective atomic number (Z_{eff}), electron density (N_{el}) and mean free path (MFP)

Z_{eff} with photon energies ranging 10^{-3}–10^{5} MeV for AM60 and AZ91 alloys have been exhibited in Figure 3. The Z_{eff} values are dependent on composition of AM60 and AZ91 alloy mediums. From Figure 3, all alloys have two peaks at 1.25 and 80 keV for AM60 and 1.25 and 20 keV for AZ91. These events occur from K absorption edges of each elements. At energy ranging start to 1.25 keV, Zeff increase rapidly as energy increases for all alloys and then decrease to 6 and 1.69 keV for AM60 and AZ91 alloys, respectively. After that Z_{eff} values increase again until 80 and 20 keV for AM60 and AZ91, respectively, and then decrease as energy increases. As energy increases until 60 MeV and 150 MeV for AM60 and AZ91, respectively, Z_{eff} values become nearly constant for both alloys. These different Z_{eff} values can be discussed on fundamental of partial interaction processes as photoelectric absorption effect, Compton scattering and pair production which main processes at low, intermediate and high energies, respectively (Dong et al., 2017; Sayyed & Elhouichet, 2017).

The N_{el} results of AM60 and AZ91 alloys at energy ranging 10^{-3}–10^{5} MeV have been calculated and presented in Figure 4. The N_{el} had same trend and behavior to Z_{eff} (Sayyed & Elhouichet, 2017) as evident from Figure 4.

Mean free path (MFP) value is suitable quantity explaining radiation attenuation which low value indicate excellent radiation shielding medium (Agar et al., 2019). From Figure 5, MFP values increase until 200 MeV of energy and then decrease with increasing energy. MFP values for AZ91 are lower than AM60. The results indicate that AZ91 alloy is better radiation shielding medium than AM60.

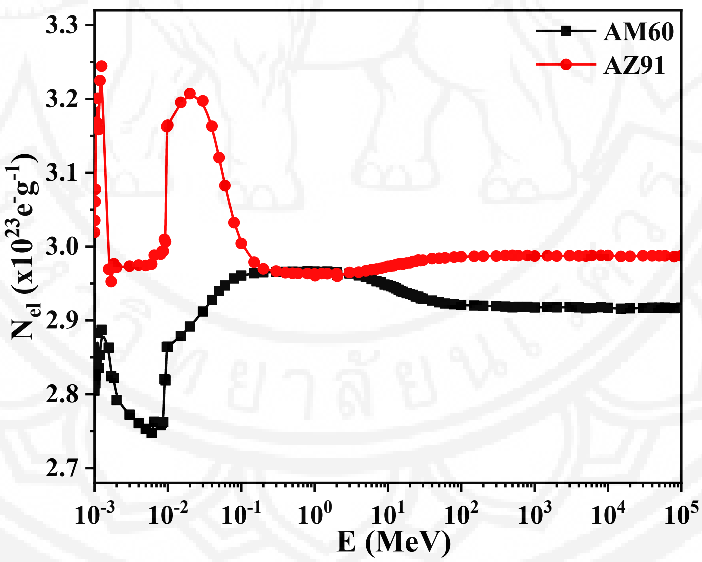

Figure 4 N_{el} VS energies for alloys at 10^{-3}–10^{5} MeV

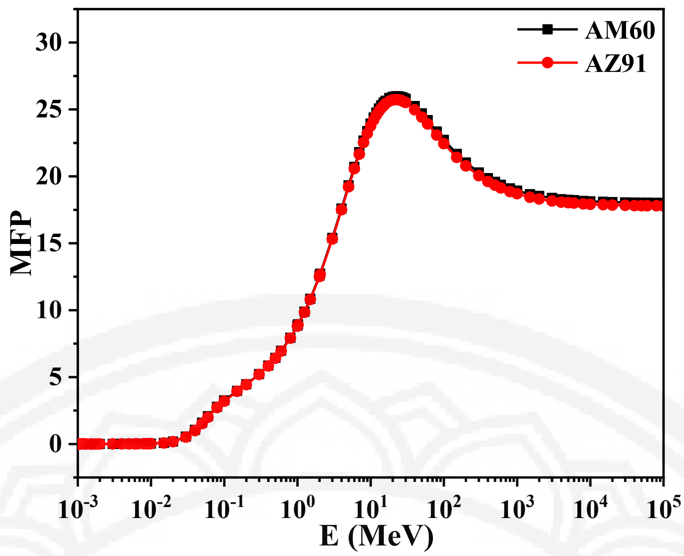

Figure 5 MFP VS energies for alloys at 10^{-3}–10^{5} MeV

3. Energy Absorption and Exposure Buildup Factors (EABF and EBF)

The value of EABF and EBF for AM60 and AZ91 alloy with photon energies at 1, 5, 10, 15, 20, 25, 30, 35 and 40 mfp have been exhibited in Figure 7. This figure presents that EABF and EBF maximum value were dependent on deep penetration and composition of alloys materials. EABF and EBF values increase until maximum value and then decrease with increasing energies. That can be discussed on fundamental of partial interaction processes. At low energies ranging, EABF and EBF values are lowest because of photons were absorbed very much. At intermediate ranging, EBF and EABF values were largest because of photons were degradant by scattering in medium. So, the highest values of EABF and EBF were shown at 40 mfp, deep penetration while the lowest values were shown at 1 mfp. At high energy ranging, photons were absorbed again (Singh & Badiger, 2014; Kaur et al., 2018; Sayyed & Elhouichet, 2017). A sharp magnitude of EABF and EBF at high energy and deep penetration were occurred because of electron–positron annihilation in material and then produced secondary photons. In really, increasing of deep penetration for medium leading to increase thickness of interacting medium as according to high equivalent atomic number (Sayyed & Elhouichet, 2017) as shown in Figure 6. Figure 8 and 9 present EABF and EBF with energies for AM60 and AZ91 at deep penetration 1, 10, 20, and 40 mfp. It found that AZ91 has lower EABF and EBF values than AM60 which indicate that AZ91 alloy is excellence radiation shielding compare with AM60.

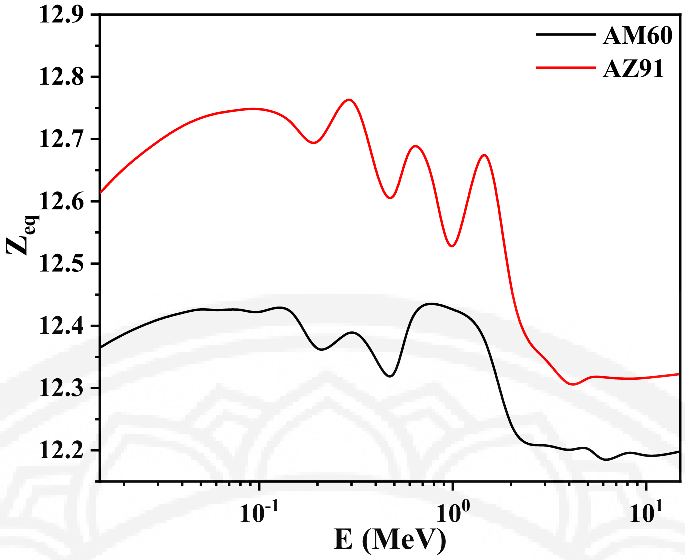

Figure 6 Z_{eq} VS photon energy for alloys at 15 keV–15 MeV

Conclusion and Suggestions

The total and partial radiation mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}), effective electron densities (N_{el}) and mean free path (MFP) have been estimated at energies ranging 10^{-3}–10^{5} MeV using WinXCom software program for AM60 and AZ91 alloys. The buildup factors (BFs) values at energy ranging 15 keV–15 MeV and deep penetration up to 40 mfp were determined using G-P fitting theory. The computation values found that AZ91 presented excellent radiation at interested energy ranging because of higher values for μ_m, Z_{eff} and N_{el} while MFP and BFs values were lower. This work could be useful for radiation shielding material.

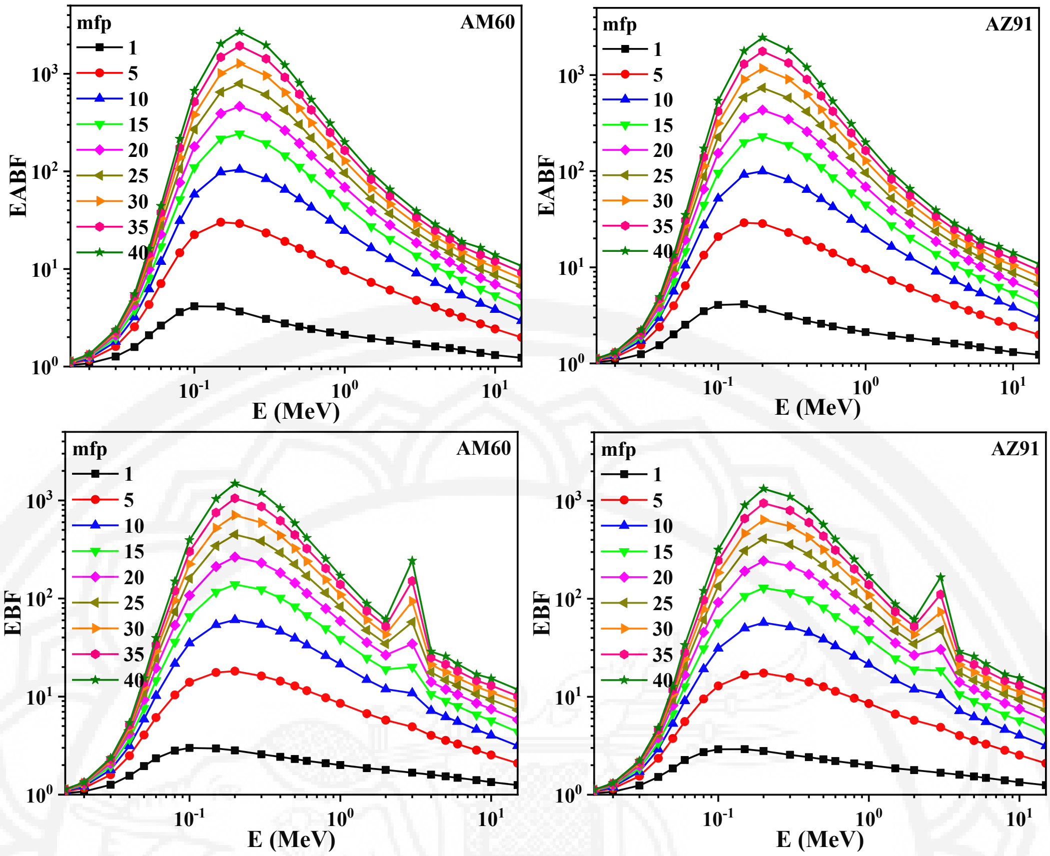

Figure 7 EABF and EBF VS photon energies at 1, 5, 10, 15, 20, 25, 30, 35 and 40 mfp

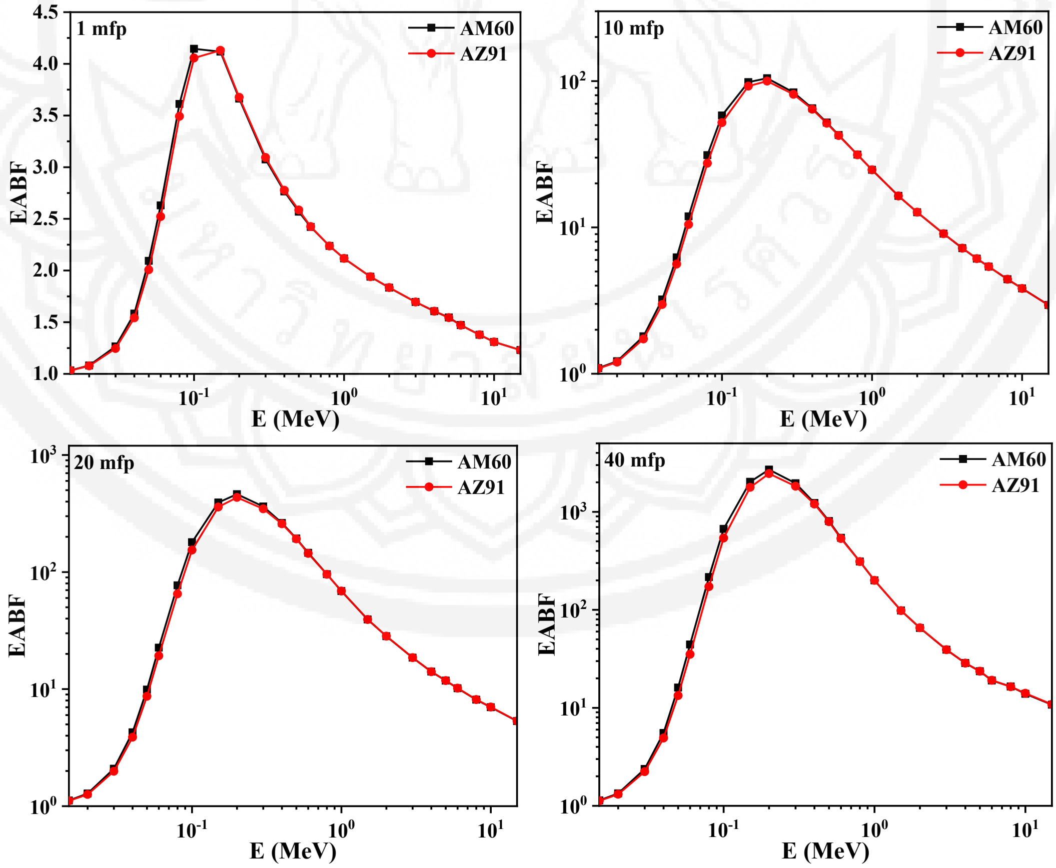

Figure 8 EABF VS photon energies at 1, 10, 20, and 40 mfp

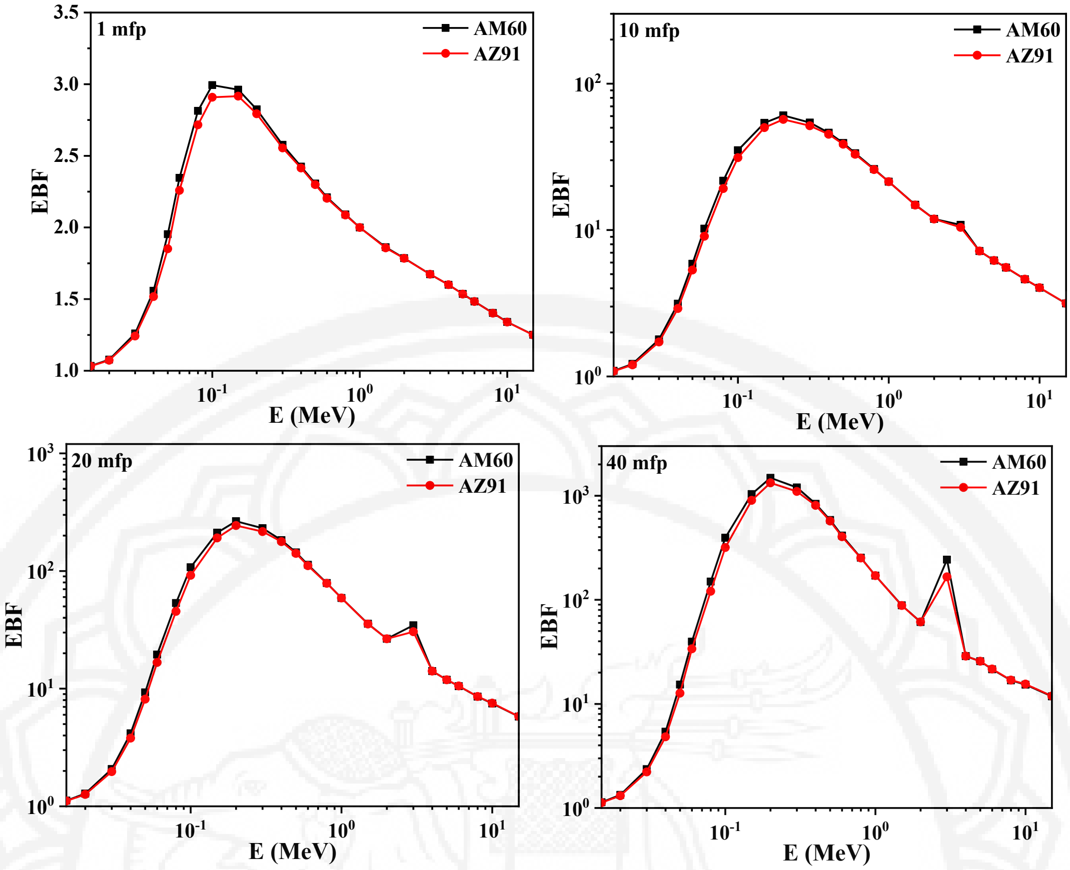

Figure 9 EBF VS photon energies at 1, 10, 20, and 40 mfp

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