THEORETICAL STUDY ON THE BASIS OF PHOTON INTERACTION PARAMETER FOR DENTAL AMALGAM

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ABSTRACT

Dental amalgam is one of the most versatile restorative materials used in dentistry, and radiation has very little effect on this material. These two factors formed the basis of the present study. Energy dispersive X-ray fluorescence spectrometer (EDXRF) was used to analyze the composition of sample material. It was found that the main composition of sample material is mercury, silver, tin and copper. The theoretical values of photon interaction parameter have been calculated by WinXCom program in the photon energy band from 1 keV to 100 GeV for sample material. The mass attenuation coefficients, effective atomic numbers, electron densities and half value layer have been obtained. The obtained values are shown graphically. The results show that, the variation of photon interaction parameters are dominance of the partial photon interaction processes and photon energy regions.

KEYWORDS: *dental amalgam, effective atomic number, electron density, mass attenuation coefficient, photon interaction*

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INTRODUCTION

Dental amalgam is a dental filling material used to fill cavities caused by tooth decay. It has been used for more than 150 years in hundreds of millions of patients around the world [1]. Dental amalgam, which contains about 50% mercury was once assumed to be inert, meaning that it released no mercury once the filling was placed. Today the US Food and Drug Administration (FDA) and other agencies acknowledge that dental amalgam releases low levels of elemental mercury vapor [2]. Still debated are the questions of whether these levels are safe, and whether the safety threshold differs among subpopulations [3].

The penetration of X-rays and gamma photons in matter were required the basic quantities parameters. It can be determined by theoretical approach. Theses parameters are mass attenuation coefficient (μ/ρ), the effective atomic number (Z_{eff}), the electron density (N_{eff}) and mean free path (MFP). These parameters have been studied for different materials [4-11]. The probability of interactions between incident photons and matter were measured in the unit mass per unit area which called mass attenuation coefficient. This parameter is required accurate values to provide essential data in various fields such as nuclear diagnostics (computerized tomography), radiation protection, nuclear medicine, radiation dosimetry, gamma ray fluorescence studies, radiation biophysics and etc.

The scattering and absorption of X-rays and gamma photons were related to the density and atomic number of an element. Hence, the density and effective atomic number were requiring in composite materials. The material composed of several elements couldn't be expressed the atomic number by a single number. Also, each of the different processes which gamma photons can interact with matter. Effective atomic number is the number that was called for composite materials and it varies with the energy [12]. Hubbell and Seltzer [13] was tabulated the theoretical values of mass attenuation coefficient. The data of this tabulated is convenient alternative to generate the attenuation data by

manual calculation. For this intent, the calculations cross sections and attenuation coefficients of any element, compound or mixture, at photon energies from 1 keV to 100 GeV was developed a computer program, XCOM, by Berger and Hubbell [13,14]. The program has since undergone a number of updates and is now available in a web version. Recently, this well-known and much-used program has been developed to the Windows platform by Gerward [15,16] and the Windows version is being called WinXCom.

In the present work, mass attenuation coefficient, effective atomic number, electron density and mean free path of dental amalgam have been calculated by theoretical approach using WinXCom program [15,16] for the photon energy range of 1 keV to 100 GeV.

MATERIALS AND METHODS

Fig. 1. The sample of dental amalgam

In this study, the dental amalgam was used as sample material, as seen in Fig. 1. The elemental composition of the sample material was analyzed by using the energy dispersive X-ray fluorescence spectrometer (EDXRF: PANalytical MiniPal 4). The elements from 100% down to the sub-ppm-level can analyze by EDXRF. The elemental compositions of dental amalgam are shown in Table 1.

Table 1. Elemental composition as fractional by weight of dental amalgam studied in the present work.

Atomic Number	20	26	29	35	47	50	80
Element	Ca	Fe	Cu	Br	Ag	Sn	Hg
Composition	0.0130	0.0010	0.1039	0.0027	0.2598	0.2059	0.4137

Theoretical values of the mass attenuation coefficients of mixture or compound have been calculated by WinXCom program [15,16], based on the mixture rule [17] can be given by the following weighted summation:

$$\mu/\rho = \sum_i w_i (\mu/\rho)_i \quad (1)$$

where ρis the mass density of the sample and w_i and $(\mu/\rho)_i$ are the fraction by weight and mass attenuation coefficient of *i*th constituent. The basic relation for calculating the effective atomic number (Z_{eff}) for all types of materials, compounds as well as mixtures can be written in terms of the fraction abundance as [18]

$$Z_{eff} = \frac{\sum_i f_i A_i (\mu/\rho)_i}{\sum_j f_j \frac{A_j}{Z_j} (\mu/\rho)_j} \quad (2)$$

where $f_i = n_i / \sum_j n_j$ is the fractional abundance of constituent element *i* (n_i is the total number of atoms, $\sum_j n_j$ is the total number of atoms present in the molecular formula), A_i is the atomic weight, Z_i is the atomic number and $(\mu/\rho)_i$ is the mass attenuation coefficient that have been obtained from the WinXCom program [15,16]. The effective electron number or electron density (N_{eff}) expressed in number of electrons per unit mass, is closely related to the effective atomic number and given by [18]

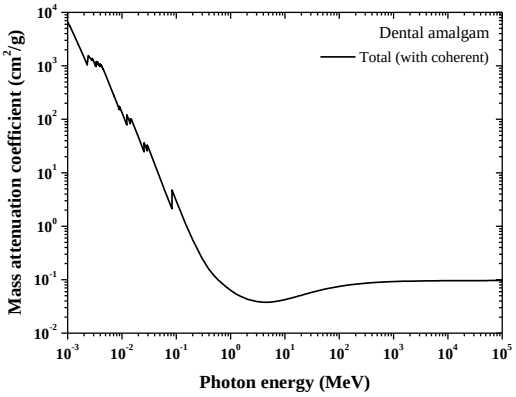
$$N_{eff} = N_A \frac{Z_{eff}}{\sum_i f_i A_i} = N_A \frac{Z_{eff}}{\langle A \rangle} \quad (3)$$

where N_A is the Avogadro's number and $\langle A \rangle = \sum_i f_i A_i$ is the average atomic number of the material. The average path between two successive interactions of photons in the intensity of 1/e which called mean free path, MFP (cm). This parameter can be calculated using the value of linear attenuation coefficient, μ (cm^{-1}), as

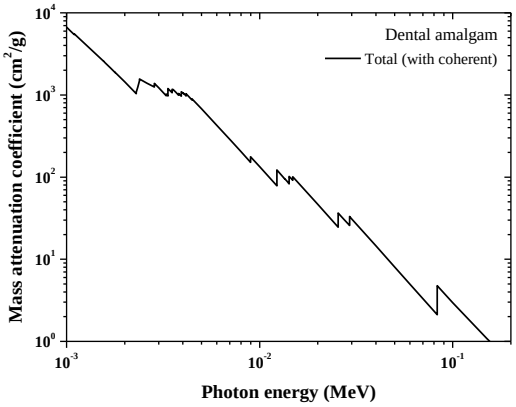
$$MFP = \frac{1}{\mu} \quad (4)$$

RESULTS AND DISCUSSION

Table 1 shows the chemical composition of dental amalgam. It was observed that the main compositions are Hg, Ag, Sn and Cu, respectively. The Mg, Ca, Fe and Br compositions are less than 1%. These compositions were used to calculate the mass attenuation coefficient, effective atomic number, electron density and mean free path. The theoretical calculations were performed using by WinXCom program in the range of photon energy from 1 keV to 100 GeV.



(a)



(b)

Fig. 2. The variation of mass attenuation coefficient of dental amalgam respect to photon energy for (a) total photon interactions (with coherent); (b) photon energy region from 1 keV–20 keV

The alterations of the mass attenuation coefficient, effective atomic number, electron density and mean free path with photon energy for dental amalgam are shown in Fig. 2-3, Fig. 4, Fig. 5 and Fig. 6, respectively, for total interaction processes. Figure 2 and Fig. 3 shows the photon interaction processes of mass attenuation coefficient which dominance with different energy regions. The different photon interaction processes were composing of partial interaction processes.

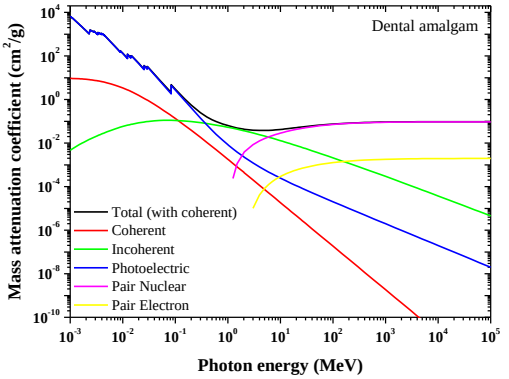


Fig. 3. The variation of mass attenuation coefficient of dental amalgam respect to photon energy 1 keV to 100 GeV for total and partial photon interactions

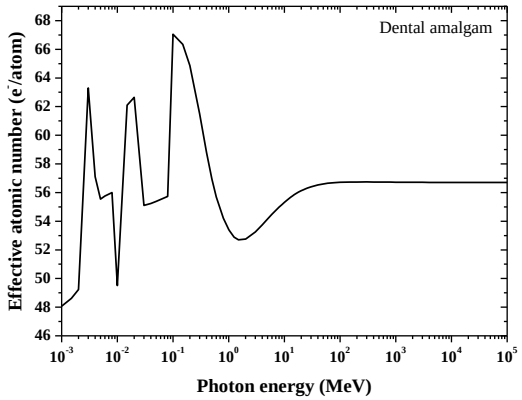


Fig. 4. The variation of effective atomic number of dental amalgam respect to photon energy 1 keV to 100 GeV

These phenomenons could be clarified by three interaction processes which is photoelectric absorption, incoherent (Compton) scattering and pair production that located at low, intermediate and high photon energies, respectively. Although, Coherent (Rayleigh) scattering was occurs mainly at low photon energies. It never plays any significant role in this connection, where photoelectric absorption is by far the most important interaction process. The discontinuous jump of radiation parameters illustrate that it arise from photoelectric effect around K-, L- and M-absorption edge of sample element compositions at low photon energies.

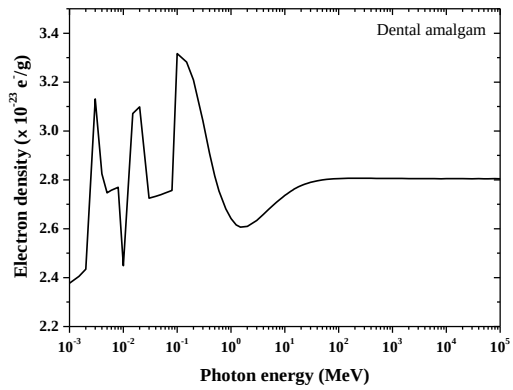


Fig. 5. The variation of electron density of dental amalgam respect to photon energy 1 keV to 100 GeV

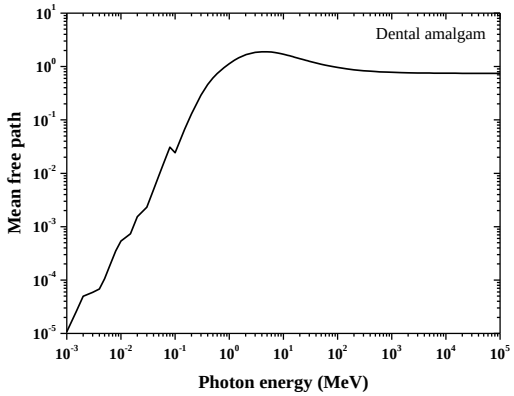


Fig. 6. The variation of mean free path of dental amalgam respect to photon energy 1 keV to 100 GeV

Figure 4 and Fig. 5 shows the effective atomic numbers and the electron densities, respectively in energies range 1 keV to 100 GeV. The significant variation in effective atomic number is due to the relative dominance of the partial photon interaction processes. The behavior of electron densities were closely related to the effective atomic numbers that obtained from relative equation (Eq. 2 and Eq. 3). The mean free path values of dental amalgam were increased with increasing photon energy as shown in Fig 6. This indicates that more photon penetrated at higher energy. At low photon energy, the variation of effective atomic numbers, electron densities and mean free path increases sharply, due to a photoelectric effect of about 1 MeV. Above 10 MeV to 100GeV, the variation of this parameter was slightly decreased.

CONCLUSION

The mass attenuation coefficient, effective atomic number, electron density and mean free path of dental amalgam at energy range 1 keV-100 GeV were calculated by the WinXCom program. For partial photon interactions, these parameters show higher photoelectric affects at the low photon energy, incoherent scattering found at medium photon energy and pair production found at higher photon energy. It can be concluded that the photon interaction of dental amalgam depends on the photon energy. At photon energy level lower than 100 keV, the parameter of radiation properties of dental amalgam has discontinuous jump which arise from photoelectric effect around absorption edge (K, L, M) of element compositions.

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