Determination attenuation coefficient and scattering of gamma ray in tissue-equivalent material

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Abstract---The photons of gamma rays emitted from radioactive sources (^{124}Am, ^{137}Cs, ^{226}Ra) at energies (60, 662, 186, 242, 295, 352, 609, 1120, 1765) keV respectively have been used to determination attenuation coefficients, mean free path and scattering cross section for two different specimen of organic compound (paraffin wax) and sodium chloride structures were measured by using measurement system of gamma ray Integrated Computer Spectrometer (ICS) has been used and the system is operated by computer according to program prepared for this purpose which is connected with sodium Iodide activated thallium detector (NaI(Tl)) with dimensions (1.5"×1.5"). the specimen was located between the source radioactive and the detector. Accumulation time was 900 seconds. The photo peak, net area and full width at half maximum (FWHM) of photo peak were measured with (USX PCI) software. The results measured and ICRU Report 44 value were compared. The variance between experimental results and human tissue of mass attenuation coefficients for organic compound and sodium chloride combination are lower than 6%.

Keywords---mass attenuation coefficients, gamma radiation, scintillation detector, mean free path, radiation sources.

Introduction

The radiation attenuation, which happens usually in the tissues that found between the organs of interest and the detector, which is one of the best important matters in use of γ-rays in nuclear medicine. Consequently, the

attenuation coefficients, described as the probability of interaction between the photon and material, in a particular way, the linear attenuation coefficient is given material per unit (cm^{-1}), and the related with mass attenuation coefficients ($\frac{\mu}{\rho}$), are also of excellent importance in matters relating to radiation and its absorption by material such as radiation dosimeter [1]. The procedures of radiological are variation with the transmitted, absorption or scattering from group organs, tissues and bone for radiation beam of incident. Thus, procedures of radiological which are provide anatomical images based on the physical appearance of the group structures. Differences in the genetic material expression designs have been studied in a tissue with completely identical and equivalent dose declaration [2]. The application of inadmissible of high radiation doses to the patients is one Problem in radiological procedures can be reduced by good approximation of the wideness of the tissues on the method of the radiation and careful select of radiation source or the radiopharmaceutical [3]. The perfect attenuation coefficient values of materials are a exact essential parameter in radiation and nuclear physics, radiation dosimeter, spectrometry, radiography, crystallography, medical, biological, agricultural, environmental and industrial [4].

Theoretical and Methods

Attenuation coefficients

The Beer-Lambert absorption law describes the possibility P of a photon energy E being transmitted done a medium [5]:

$$P = I/I_0 = e^{-(\mu \times x)} \qquad (1)$$

$$\mu = (\ln(I_0/I)/x) \qquad (2)$$

$$P = I/I_0 = e^{-(\mu/\rho \times \rho x)} \qquad (3)$$

$$\mu/\rho = ((\ln I_0/I)/\rho x) \qquad (4)$$

where I is the intensity of the attenuated beam, I_0 is the initial intensity of the beam, x is the thickness of the attenuating material, and μ is the linear attenuation coefficients (cm^{-1}), The mass attenuation coefficients (cm^2/g) were obtained from Eq. (2) by dividing the density of the corresponding samples as follows,

$$\mu/\rho = ((\ln I_0/I)/\rho x) \qquad (5)$$

where ρ is the density of material, The relation of the incident I_0 and transmitted I intensities refers to the transmission probability when beam photons are incident upon the material? The mass attenuation coefficient $(\mu_m = \mu/\rho)$ refer to all process's photon is absorption or scattering.

The cross section of scattering is related to the mass attenuation coefficient [6]:

$$\sigma_{Total} = (\mu/\rho) \times (M/N_A) \quad (6)$$

Where M is the atomic weight (g/mol), N_A Avogadro's number (atoms/mol).

Mean Free Path (mfp)

The distance between two interaction consecutives of one particle movement through the organ of given specimen before interaction with material is called the mean free path, and is considered by the following equation [7]:

$$\lambda(cm) = \int_0^\infty x \cdot \exp(\mu x) dx \Big/ \int_0^\infty \exp(\mu x) dx = 1/\mu \qquad (7)$$

Methods and Materials

Sample Preparation

The organic compound ($C_{31}H_{64}$) and sodium chloride (NaCl) of Two mixtures to produce tissue equivalent material were prepared. The organic compound was heated at 70 C^o. Then, sodium chloride was supplement into the organic compound. The combinations were decanted to produced template with measurement of 5cm×5 cm×0.5cm. Both specimens have variance percentage of sodium chloride additional to organic compound. The acceptable choice of the organic compound ($C_{31}H_{64}$) and sodium chloride (NaCl) to propose preparation a tissue equivalent material is necessary to allow the fabrication of capable essential materials. Also, these materials require agreement with the essential characteristic of calculated atomic cross section, electron density, molecular cross section and mass in order to simulator the object tissue effectively. For this aim of the present work, two specimen of combination organic compound and NaCl were prepared. The specimen was denoted by specimen A and B. These specimens were completed to mimic soft tissue of human, while another C and D specimen were completed to mimic bone tissue. These four specimens were completed in the laboratory. Specimen were indicated and identified as A, B,C and D showed in Figure (1), For soft tissue equivalent A and B specimen, the fundamental materials composition, physical properties and percentage amount of NaCl in A and B specimen is ($C_{31}H_{64}$NaCl, 0.5 cm, 1.08 g/cm^3, 25%) respectively. While for bone tissue equivalent C and D specimen, , the fundamental materials composition, physical properties and the ratio of NaCl in C and D specimen is ($C_{31}H_{64}$NaCl, 0.5 cm, 1.4 g/cm^3, 40%) respectively. The density measurements of the tissues were carried out with a precision scale to measure the weight M, and volume by using a vernier caliper.

Figure 1. Tissue equivalent specimen produced A, B, C and D paraffin wax-based materials

Experimental Setup and measurements

The gamma ray sources (^{241}Am, ^{137}Cs, ^{226}Ra) and the gamma ray measurement system Integrated Computer Spectrometer (ICS) has been used and the system is operated by computer according to program prepared for this purpose, associated with the scintillation detector were utilized, Shown in Figures (2), the system contains a primary amplifier and a main amplifier, equipped with an alumina NaI(Tl) voltage. And a multi-channel analyzer, this system is related to a computer for the resolution of operating it, reading its measurements and analyzing the results. It was obtained a narrow beam of gamma rays using a rectangular lead sight (20cm×10cm×5cm), passes the rays coming from the radioactive source pass through it. (15mm) hole diameter.
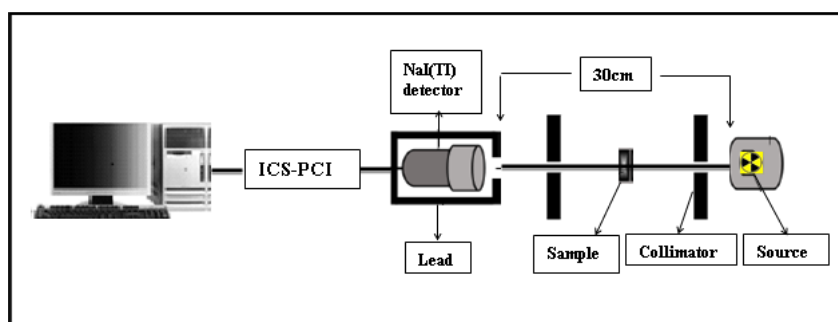

Figure 2. Set up experimental

The attenuation coefficients for organic compound tissue equivalent specimens which represents soft and bone tissue were determined for energies (60 keV - 1.765 MeV) by using Beer- Lambert law. The energies were selected because these energies range are be applied in medical imaging, nuclear medicine department and radiotherapy. The determination value was completed utilizing a NaI(Tl) detector for γ-ray spectrometry. The detector was protected with a shield of lead covering to lower radiation of scattered arriving from the radiation source directly. To determination of attenuation was measured utilizing NaI(Tl) detector. The specimens were putting between radiation source and detector. Accumulation time was set 900 seconds. The photo peak, net area and full width at half maximum (FWHM) of photo peak were measured utilizing (USX PCI) program.

radioactive sources utilized of γ-ray energies were Am-241 (60keV), Cs-137 (662keV), and Ra-226 (186 - 1765 keV) to determinate the attenuation coefficients of each specimen. Figures (3),(4) and (5) shows the result of spectrum obtained from (USX PCI) software for Am-241, Cs-137 and Ra-226.
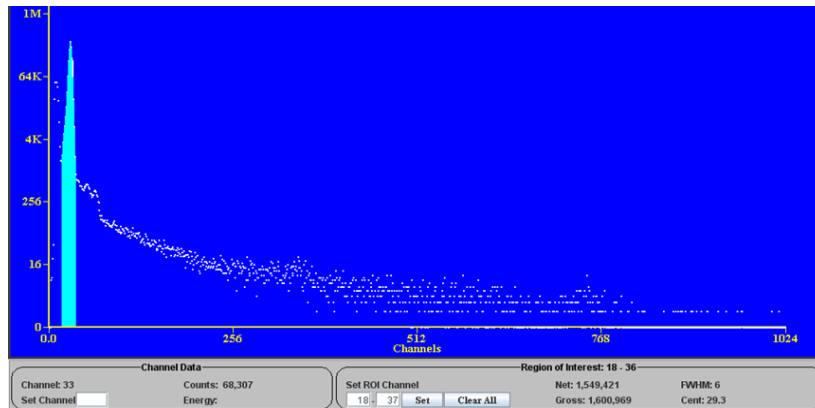

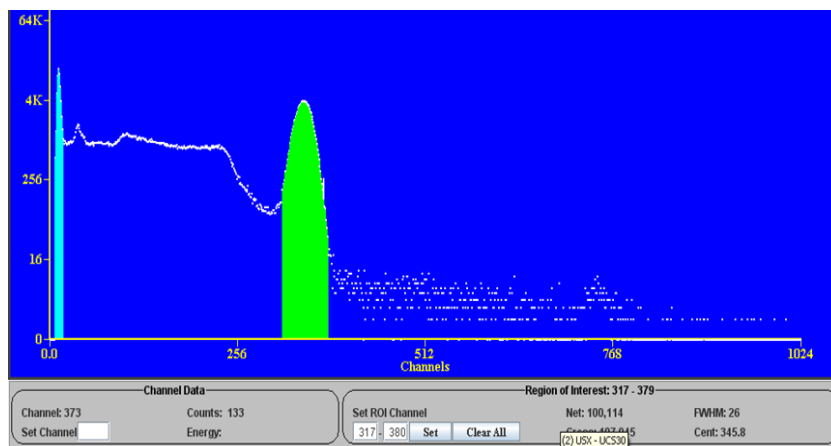Figure 3. The Am-241 spectrum obtained for γ-ray spectroscopy.

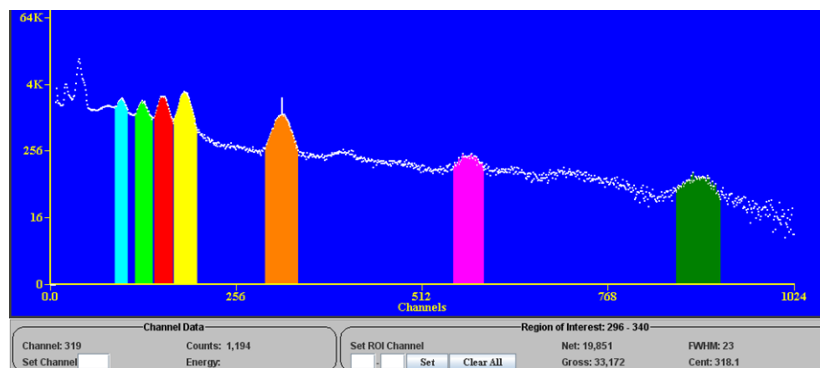Figure 4. The Cs-137 spectrum obtained for γ-ray spectroscopy

Figure 5. The Ra-226 spectrum obtained for γ-ray spectroscopy.

Results and Discussion

The linear attenuation coefficients, mean free path, mass attenuation coefficients and scattering cross section for soft and bone tissue equivalent materials were determined. The results are presented in Table (1) and Table (2).

Table 1. linear attenuation coefficients, mass attenuation coefficients, mean free path and scattering cross section of soft tissue equivalent samples

E (keV)	60	186	242	295	352	609	662	1120	1765
μ (cm⁻¹)	0.22	0.15	0.133	0.123	0.12	0.093	0.090	0.073	0.061
μₘ (cm²/g)	0.21	0.14	0.12	0.11	0.10	0.086	0.084	0.068	0.057
λ (cm)	4.48	6.80	7.51	8.09	8.64	10.66	11.01	13.52	16.21
σ (barn)	117	77.6	70.3	65.2	61.0	49.49	47.92	39.02	32.55

Table 1. linear attenuation coefficients, mass attenuation coefficients, mean free path and scattering cross section of bone tissue equivalent samples

E (keV)	60	186	242	295	352	609	662	1120	1765
μ (cm⁻¹)	0.35	0.20	0.17	0.16	0.14	0.112	0.108	0.086	0.071
μₘ (cm²/g)	0.25	0.14	0.12	0.11	0.10	0.080	0.077	0.061	0.051
λ (cm)	2.89	5.10	5.80	6.37	6.93	8.906	9.243	11.59	13.93
σ (barn)	117	66.5	58.5	53.2	48.9	38.09	36.70	29.26	24.35

Therefore, organic compound and sodium chloride as tissue equivalent materials can us to studied as alternative material for smooth and hard tissue which utilizes in nuclear medicine and radiotherapy, The difference between mass attenuation coefficient of determination and ICRU-44 values were measured γ-ray energies of standard radionuclide utilized. Differences under 6% were noticed in figure (6) of soft tissue materials specimen. It indications that materials have a very good relation accept [8].
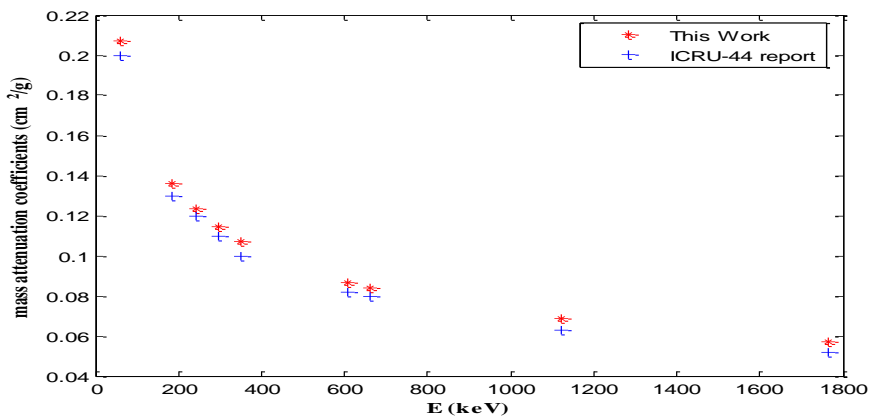

Figure 6. comprehensive of mass attenuation coefficients.

Also for bone tissue equivalent material show in figure (7). It is perfect that attenuation coefficient variation with chemical content and photon energy. Therefore, reduction in mass attenuation coefficient due to possibility of absorption decreases with increasing photon energies. uncertainty of experimental values variation with area photo peak uncertainties, uncertainties of thickness measurements, experimental set up and count statistics, linear attenuation coefficient, mean free path and total atomic cross-section were determinate of all specimens at γ-ray energies.
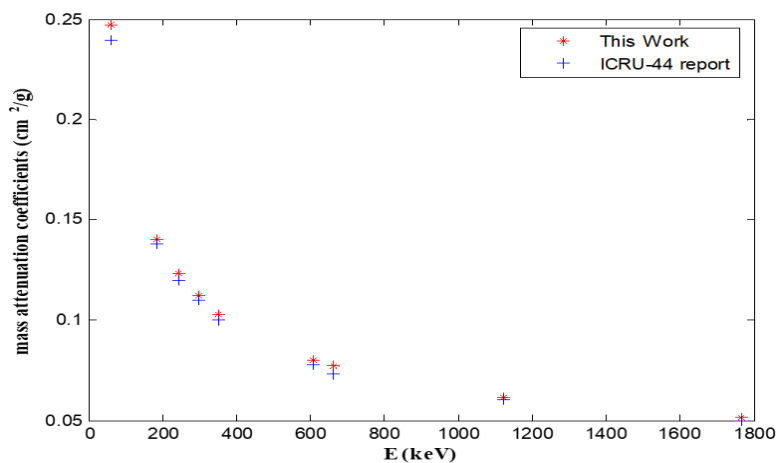

Figure 7. Variation of mass attenuation coefficients

mean free path of organic compound and sodium chloride structures increases with γ-ray energies show in Figures (8) and (9). Because of decrease in possibility of interaction γ-rays with material and increase the energies of γ-ray , the good agreement between experimental and ICRU-44 values. Gives a clear picture of possibility of using this regularity of sodium chloride in the organic compound were mixed as the combination of all atomic elements are not matching, that a variation in chemical environments and deformation. This influence may change value obtained from the experiment. However the influences are not take into consideration when the values were calculated by XCOM program and semi empirical relations. For this reason values of experimental for soft and bone tissue equivalent specimens different from values of computed. This variance between experimental and theoretical value influence appears in μ_m of the values observed from experiment and calculation as a result of set up of experimental and its efficiency errors of counting.
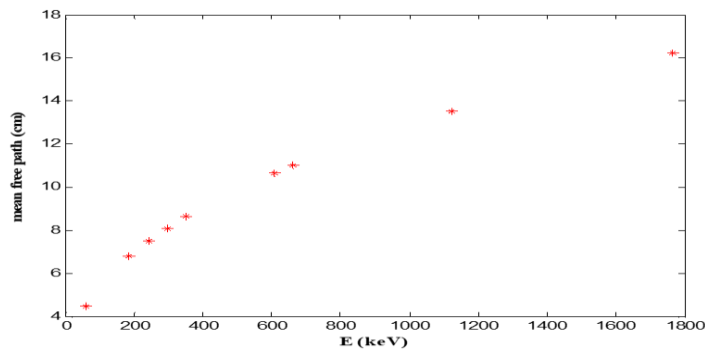
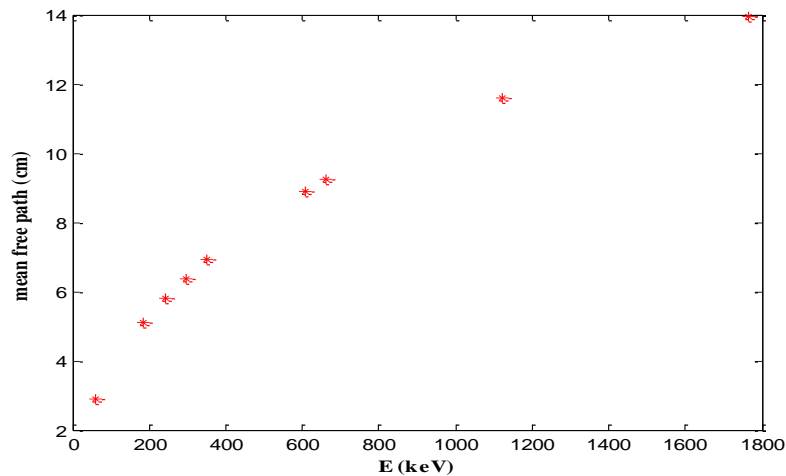Figure 7. mean free path of soft tissue equivalent materials

Figure 9. mean free path of bone tissue equivalent materials.

Conclusion

Study of experimental were approved to measure the mass attenuation coefficients and some other parameter related with γ-ray interaction of organic compound and sodium chloride to presents tissue equivalent materials specimens. In this study, the mass attenuation coefficient values are related to the physical and chemical structure for atomic elements in specimen. The attenuation coefficients values for all specimen decrease when increased γ-ray energy. all soft and bone tissue equivalent specimens have physical properties nearby human tissue, and the percentage of variance lower than 6%. All physical properties of soft and bone tissue equivalent measured will improve the understanding how variation the attenuation coefficients with the difference of the atomic number and electronic density of the percentage variance of sodium chloride mixed into organic compound. Also this study refer to can used organic compound and sodium chloride to presents tissue equivalent materials for phantom fabrication.

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