JOURNAL OF SCIENCE
SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University | http://www.saujs.sakarya.edu.tr/

Title: A Study on the Gamma-ray Attenuation Parameters of Some Commercial Salt Samples

Authors: Canel Eke
Recieved: 2019-05-27 11:33:01

Accepted: 2020-03-10 11:20:56

Article Type: Research Article
Volume: 24
Issue: 2
Month: April
Year: 2020
Pages: 412-423

How to cite
Canel Eke; (2020), A Study on the Gamma-ray Attenuation Parameters of Some Commercial Salt Samples. Sakarya University Journal of Science, 24(2), 412-423, DOI: 10.16984/saufenbilder.570480
Access link
http://www.saujs.sakarya.edu.tr/tr/issue/52471/570480

Sakarya University Journal of Science 24(2), 412-423, 2020

SAKARYA UNIVERSITY

A Study on the Gamma-ray Attenuation Parameters of Some Commercial Salt Samples

Canel EKE[*1]

Abstract

The purpose of this study is to calculate self-attenuation correction factors, linear (LAC) /mass attenuation coefficients (MAC), half value layers (HVL) and tenth value layers (TVL) of different brands of commercial salt samples using gamma-ray spectrometry equipped with high resolution germanium (HpGe) detector. The gamma-rays emissions of ^{22}Na, ^{60}Co, ^{133}Ba and ^{137}Cs point sources were counted with/without sample. The obtained gamma-ray spectra were analyzed using computer software. Self-attenuation correction factors and gamma-ray attenuation parameters of eleven different brands of commercial salt sample were calculated. The experimental MACs of salt samples were compared with those of NaCl compound utilizing WinXCom software.

Keywords: Self-attenuation correction factor, gamma-ray attenuation parameter, gamma-ray spectrometry, salt samples

1. INTRODUCTION

Gamma-ray spectrometry is used to determine activity concentrations of natural and artificial radionuclides in environmental materials. The accurate and precise determination of radioactivity concentration in samples is important in many areas including radioactive waste management, health physics etc. [1]. Several correction factors have to be determined to obtain reliable activity concentrations. One of them is the self-attenuation correction factor which is described as the ratio a reference specimen count rate to that of the sample [2] The self-attenuation correction factor is calculated theoretically [3], experimentally [1,4] and by simulation methods [2, 5, 6, 7]. Usually, the self-attenuation correction factor is calculated using the Cutshall transmission method [4]. To obtain the most precise results the experimental approach should be used, in which point sources are placed upon the sample or reference specimen placed on the head of the detector [4, 6]. Values of self-attenuation correction factors vary depending on the density, geometry, the chemical

* Corresponding Author. ceke@akdeniz.edu.tr
[1] Akdeniz University, Department of Mathematics and Science Education, Division of Physics Education, Antalya, Turkey. ORCID: 0000-0002-6672-6467

composition of the measured items as well as their attenuation coefficients [1, 6, 8].

The linear attenuation coefficient (LAC) is defined as the probability of interaction per distance unit [9]. Photons interact with material by three processes, namely the Photoelectric Effect, the Compton Effect and the Pair Production. The linear attenuation coefficient is the sum of the probabilities of these interactions as shown in the following equation:

$$\mu = \tau + \sigma + \kappa \quad (1)$$

where τ, σ and κ are the aforementioned interactions, respectively. The Photoelectric Effect is dominant at low gamma-ray energies, the Compton Effect is dominant at mid-gamma ray energies, and the Pair Production is dominant at $E_\gamma > 1.022$ MeV [11]. The mass attenuation coefficient (MAC) depends on the density of the sample.

There are various methods to obtain gamma-ray attenuation parameters in different areas. Gamma-ray attenuation parameters were calculated for soil [13], cane sugar of milk [14], diethylene glycol dissolved in ethyl alcohol [15], naphthalene dissolved in ethanol [16], dilute aqueous solutions of sugar ($C_6H_{12}O_6$) [17], manganese (II) chloride [18], potassium chloride [19], ammonium sulfate [20], NaCl [31], lead nitrate [22], etc. [23, 24]. Furthermore, biological compounds [25], some amino acids [26], alcohol-soluble compounds [27, 28], medical plants [29, 30], different wood materials with different densities [31], environmental bulk sample 32], biological and geological samples [33], and many more. In literature, aqueous solution of salts samples were studied using different methods to calculate gamma-ray attenuation parameters [23, 24, 37, 38].

Gamma-ray attenuation parameters are highly relevant in radiation protection [20] because investigation of gamma-ray parameters of materials is important for applicability in science, technology, human health dosimetry, radiography, radiation shielding, etc. [23, 37]. In view of the importance of the attenuation parameters, the purpose of this study is to calculate gamma-ray attenuation parameters of salt samples and to give examples of application of the Cutshall et al. [4] transmission method using gamma-ray spectrometry. Also the experimental mass attenuation coefficients will be compared with obtained mass attenuation coefficients using WinXCom software [40] to check the accuracy of the results of this study.

2. MATERIAL AND METHOD

In this study to calculate gamma-ray parameters, eleven salt samples were used. Except for S6 which is dishwasher salt, the others are different brands commercial edible salts. S1, S2, S3, S5 and S7 are not refined while S4, S8, S9, S10 and S11 are refined. Densities of the samples are shown in Table-1 and Table-2. Densities (ρ) of samples were calculated using $\rho = m/V$ equation, where m is masses of the salt samples V is the volume of the salt samples.

The γ-ray emissions of radioactive point sources ^{22}Na (1274 keV), ^{60}Co (1173 and 1332 keV), ^{133}Ba (81, 276, 302, 356 and 383 keV) and ^{137}Cs (662 keV) were counted 1000 seconds using high purity germanium (HpGe) detector to calculate self-attenuation correction factors, linear-mass attenuation coefficients, HVL and TVL of eleven different brands of salt samples. The activities of these point sources are approximately 1 μCi (37 kBq). The samples were put into 100 ml plastic container; its diameter and height are 61 mm and 53 mm, respectively. The samples were not been sieved because their crystals get same size but samples were shaked to increase density before the measurements. Gamma-ray spectra were analyzed using Maestro-32 software [34]. Wolfram Mathematica-8 [36] software was used in calculating the self-attenuation correction factors of sample versus energy referring to ultrapure water and air fitting function.

The self-attenuation correction factor C_f is calculated using the following well know equation which is called the Cutshall transmission formula [4],

$$C_f = \frac{In\left(\frac{I}{I_0}\right)}{\frac{I}{I_0} - 1} \quad (2)$$

where, I is the count number of source inside the container with the sample and I_0 is the count number of the source inside the container (without sample). Firstly, the container was counted empty then it was filled with ultrapure water when the count number without sample was counted.

The LAC is calculated using the well-known (Lambert – Beer's Law) equation [10, 11],

$$I = I_0 e^{-\mu_l x} \quad (3)$$

$$\mu_l = -\frac{\ln\left(\frac{I}{I_0}\right)}{x} \quad (4)$$

where, μ_l is the LAC of the sample, I is the number of incident photons counts passing through absorber material, I_0 is the number of incident photons counts passing through without absorber material, viz., the empty sample container, and x is the thickness of the absorber material, viz., the sample.

The mass attenuation coefficient (MAC) depends on the density of the sample and is calculated using the following equation [9]:

$$\mu_m = \frac{\mu_l}{\rho} \quad (5)$$

where, μ_m is the mass attenuation coefficient of the sample, and ρ is the density of the sample. Also MACs were calculated using WinXCom software [40]. Total cross-sections and attenuation coefficients also partial cross-sections for incoherent and coherent scattering, photoelectric absorption and pair production can be obtained using WinXCom for elements, compounds or mixtures [40].

Half value layer (HVL) and tenth value layer (TVL) are generally relevant in gamma-ray shielding enforcement considerations. The HVL is described as thickness of shielding materials which reduces the radiation intensity by a factor of two whilst TVL reduces the intensity by a factor of 10 [12]. The HVL and TVL are calculated using following equations,

$$HVL = \frac{In2}{\mu_l} \quad (6)$$

$$TVL = \frac{In10}{\mu_l} \quad (7)$$

3. RESULTS AND DISCUSSION

Self-attenuation correction factors of salt samples referring to air or ultrapure water environment, linear attenuation coefficients (LAC), mass attenuation coefficients (MAC), half value layers (HVL) and tenth value layers (TVL) of salt samples are shown in Tables 1, 2 and 3, respectively. As an example, the self-attenuation correction factor versus energy graphic referring to air sample and ultrapure water sample, variation of the LACs as a function of the γ-ray energy of sample-1 and sample-4, variation of the MACs as a function of the γ-ray energy of sample-1 and sample-4, their transmission rates of sample-1 and sample-4 at different γ-ray energies are shown in Figures 1, 2, 3, 4 and 5, respectively.

The self-attenuation correction factor of salt samples referring to air is greater than that referring to ultrapure water as shown in Figure 1. Because densities of salt samples are greater than that of air and the density of water is higher than air also the self-attenuation correction factor mainly depends on the chemical components and on the integral density of the investigated material [35]. The function of the self-attenuation correction factor versus the energy referring to the air sample and ultrapure water sample was fitted using the fitting function $C_f=aE^{-b}+c$ where E is the gamma-ray energy, and a, b and c are the fitting parameters.

The LACs and MACs were fitted by the $y=ax^{-b}$ fitting function where y is the LAC or MAC, respectively, x is the gamma-ray energy, a and b are the best fit parameters. Because MACs are influenced by the density of the sample they are lower than the LACs. As shown in Figure 4, the values of MACs of sample-1 and sample-4 are nearly equal although the density of sample-1 is 1.286 g/cm^3 and 1.651 g/cm^3 for sample-4. Conversely, the LACs of sample-1 and sample-4 are different since the LACs depend on the thickness of the samples. Although the thicknesses of the samples are equal in this experiment, the LACs are different. The LACs not only depend on density but also nature of samples. The MACs indicate similar values at certain energy for all samples so the compositions of salt samples are also similar. MACs of NaCl compound were calculated using WinXCom software [40] because the Na and Cl are main elements while the Mg, S, K, Ca, Mn, Fe, Br and Si are trace elements in commercial edible salt samples [39]. The MACs of salt samples obtained experimentally are lower than the results of MACs of NaCl compound obtained from WinXCom software [40] as shown in Table 4. These disparities in the results of the experimentally calculated and obtained from WinXCom [40] may be due about experimental setup especially from narrow-beam geometry in the source- detector settings [41].

The HVL and TVL increase with increasing incident gamma-ray energy (see Table 3). Thus, the transmission rate changes with the gamma-ray energy as shown in Figures 4 and 5 and the transmission rates of the sample-1 and sample-4 decrease with increasing thickness of sample.

Table 1. Self attenuation correction factors of salt samples referring to air

Sample No	Density (g/cm^3)	^{133}Ba (keV)					^{137}Cs (keV)	^{60}Co (keV)	^{22}Na (keV)	^{60}Co (keV)
		81	276	302	356	383	662	1173	1274	1332
1	1.286	1.666±0.024	1.299±0.038	1.288±0.019	1.279±0.009	1.280±0.032	1.211±0.007	1.160±0.009	1.154±0.008	1.143±0.009
2	1.264	1.667±0.024	1.313±0.039	1.311±0.020	1.283±0.009	1.277±0.032	1.224±0.007	1.162±0.009	1.160±0.008	1.148±0.009
3	1.480	1.806±0.030	1.381±0.044	1.358±0.022	1.343±0.009	1.336±0.035	1.266±0.008	1.197±0.010	1.180±0.008	1.175±0.009
4	1.651	1.889±0.033	1.442±0.049	1.397±0.023	1.374±0.010	1.384±0.038	1.290±0.008	1.212±0.010	1.202±0.009	1.191±0.009
5	1.486	1.802±0.030	1.353±0.042	1.349±0.021	1.336±0.009	1.339±0.036	1.250±0.008	1.196±0.010	1.182±0.008	1.178±0.009
6	1.400	1.782±0.029	1.349±0.042	1.349±0.022	1.328±0.009	1.331±0.035	1.270±0.008	1.194±0.010	1.182±0.008	1.176±0.009
7	1.434	1.762±0.027	1.333±0.040	1.353±0.022	1.326±0.009	1.346±0.036	1.257±0.008	1.188±0.010	1.184±0.008	1.172±0.009
8	1.586	1.829±0.030	1.397±0.044	1.367±0.022	1.361±0.010	1.367±0.037	1.284±0.008	1.210±0.010	1.191±0.009	1.193±0.009
9	1.579	1.820±0.030	1.402±0.046	1.378±0/023	1.342±0.009	1.334±0.035	1.267±0.008	1.195±0.010	1.181±0.008	1.174±0.009
10	1.615	1.863±0.032	1.397±0.045	1.390±0.023	1.352±0.010	1.398±0.040	1.267±0.008	1.201±0.010	1.186±0.008	1.183±0.009
11	1.631	1.868±0.032	1.412±0.046	1.385±0.023	1.365±0.010	1.386±0.039	1.279±0.008	1.207±0.010	1.189±0.008	1.184±0.009

Table 2. Self attenuation correction factors of salt samples referring to ultrapure water

Sample No	Density (g/cm^3)	^{133}Ba (keV)					^{137}Cs (keV)	^{60}Co (keV)	^{22}Na (keV)	^{60}Co (keV)
		81	**276**	**302**	**356**	**383**	**662**	**1173**	**1274**	**1332**
1	1.286	1.174±0.019	0.989±0.034	0.990±0.017	0.991±0.008	1.002±0.029	0.986±0.007	0.993±0.008	0.998±0.008	0.993±0.008
2	1.264	1.174±0.019	1.001±0.035	1.009±0.018	0.994±0.008	0.999±0.029	0.997±0.007	0.995±0.009	1.003±0.008	0.998±0.008
3	1.480	1.289±0.024	1.059±0.039	1.049±0.019	1.045±0.008	1.050±0.032	1.033±0.007	1.027±0.009	1.021±0.008	1.023±0.009
4	1.651	1.357±0.026	1.110±0.043	1.082±0.020	1.072±0.009	1.091±0.034	1.054±0.007	1.040±0.009	1.041±0.008	1.037±0.009
5	1.486	1.285±0.024	1.034±0.037	1.041±0.019	1.039±0.008	1.052±0.032	1.020±0.007	1.026±0.009	1.023±0.008	1.025±0.009
6	1.400	1.269±0.023	1.031±0.036	1.041±0.019	1.033±0.008	1.046±0.031	1.038±0.007	1.024±0.009	1.024±0.008	1.024±0.009
7	1.434	1.252±0.022	1.018±0.035	1.045±0.019	1.031±0.008	1.059±0.032	1.026±0.007	1.018±0.009	1.026±0.008	1.020±0.009
8	1.586	1.307±0.024	1.072±0.039	1.057±0.019	1.061±0.009	1.077±0.033	1.050±0.007	1.038±0.009	1.032±0.008	1.039±0.009
9	1.579	1.300±0.024	1.076±0.040	1.066±0.020	1.045±0.008	1.048±0.031	1.035±0.007	1.025±0.009	1.022±0.008	1.022±0.009
10	1.615	1.336±0.026	1.072±0.040	1.076±0.020	1.053±0.008	1.103±0.035	1.037±0.007	1.030±0.009	1.027±0.008	1.030±0.009
11	1.631	1.341±0.026	1.084±0.040	1.072±0.020	1.064±0.009	1.093±0.034	1.045±0.007	1.036±0.009	1.030±0.008	1.032±0.009

Table 3. Linear attenuation coefficient (LAC), mass attenuation coefficient (MAC), half value layer (HVL) and tenth value layer (TVL) of salt samples

Sample No			**^{133}Ba (keV)**			**^{137}Cs (keV)**	**^{60}Co (keV)**	**^{22}Na (keV)**	**^{60}Co (keV)**
	81	**276**	**302**	**356**	**383**	**662**	**1173**	**1274**	**1332**
S1									
μ_l (cm^{-1})	0.212±0.005	0.103±0.006	0.100±0.003	0.097±0.002	0.097±0.005	0.075±0.002	0.058±0.002	0.055±0.002	0.051±0.002
μ_m(cm^2/g)	0.165±0.004	0.080±0.005	0.078±0.003	0.075±0.002	0.076±0.004	0.058±0.001	0.045±0.001	0.043±0.001	0.040±0.001
HVL (cm)	3.264±0.074	6.711±0.038	6.941±0.237	7.149±0.164	7.128±0.372	9.271±0.225	12.048±0.386	12.539±0.384	13.471±0.463
TVL (cm)	10.841±0.247	22.295±1.256	23.056±0.789	23.748±0.546	23.678±1.236	30.799±0.747	40.023±1.282	41.653±1.276	44.750±1.472
S2									
μ_l (cm^{-1})	0.212±0.005	0.108±0.006	0.107±0.004	0.098±0.002	0.096±0.005	0.079±0.002	0.058±0.002	0.057±0.002	0.053±0.002
μ_m(cm^2/g)	0.168±0.004	0.085±0.005	0.085±0.003	0.078±0.002	0.076±0.004	0.062±0.001	0.046±0.001	0.045±0.001	0.042±0.001
HVL (cm)	3.262±0.074	6.420±0.352	6.455±0.254	7.062±0.177	7.198±0.375	8.782±0.210	11.886±0.378	12.061±0.362	12.978±0.443
TVL (cm)	10.838±0.246	21.328±1.168	21.445±0.842	23.460±0.589	23.911±1.245	29.175±0.697	39.485±1.256	40.066±1.202	43.113±1.472
S3									
μ_l (cm^{-1})	0.250±0.006	0.129±0.006	0.122±0.004	0.117±0.003	0.115±0.005	0.093±0.002	0.070±0.002	0.064±0.002	0.063±0.002
μ_m(cm^2/g)	0.169±0.004	0.087±0.004	0.082±0.003	0.079±0.002	0.078±0.004	0.063±0.001	0.047±0.001	0.043±0.001	0.042±0.001
HVL (cm)	2.768±0.062	5.361±0.268	5.683±0.209	5.910±0.140	6.020±0.284	7.479±0.170	9.885±0.284	10.800±0.306	11.088±0.363
TVL (cm)	9.194±0.207	17.809±0.891	18.879±0.696	19.634±0.465	19.998±0.943	24.844±0.566	32.838±0.942	35.877±1.015	36.835±1.206
S4									
μ_l (cm^{-1})	0.272±0.006	0.148±0.007	0.134±0.005	0.127±0.003	0.130±0.006	0.100±0.002	0.075±0.002	0.072±0.002	0.068±0.002
μ_m(cm^2/g)	0.165±0.004	0.090±0.004	0.081±0.002	0.077±0.002	0.079±0.004	0.061±0.001	0.045±0.001	0.043±0.001	0.041±0.001
HVL (cm)	2.547±0.057	4.688±0.220	5.175±0.187	5.463±0.129	5.333±0.237	6.904±0.154	9.244±0.258	9.686±0.261	10.204±0.334
TVL (cm)	8.461±0.191	15.574±0.731	17.190±0.621	18.148±0.429	17.717±0.788	22.936±0.512	30.709±0.856	32.177±0.868	33.898±1.111
S5									
μ_l (cm^{-1})	0.249±0.006	0.120±0.006	0.119±0.005	0.115±0.003	0.116±0.005	0.088±0.002	0.070±0.002	0.065±0.002	0.064±0.002
μ_m(cm^2/g)	0.168±0.004	0.081±0.004	0.080±0.003	0.077±0.002	0.078±0.004	0.059±0.001	0.047±0.001	0.044±0.001	0.043±0.001
HVL (cm)	2.781±0.063	5.758±0.297	5.821±0.232	6.026±0.149	5.977±0.283	7.911±0.183	9.949±0.288	10.681±0.301	10.909±0.359
TVL (cm)	9.237±0.209	19.128±0.988	19.337±0.772	20.017±0.495	19.855±0.941	26.280±0.606	33.051±0.957	35.482±0.999	36.239±1.194
S6									
μ_l (cm^{-1})	0.244±0.006	0.119±0.006	0.119±0.005	0.113±0.003	0.114±0.005	0.094±0.002	0.069±0.002	0.065±0.002	0.063±0.002
μ_m(cm^2/g)	0.174±0.004	0.085±0.004	0.085±0.003	0.080±0.002	0.081±0.004	0.067±0.002	0.049±0.001	0.046±0.001	0.045±0.001
HVL (cm)	2.840±0.064	5.820±0.300	5.812±0.224	6.159±0.151	6.095±0.289	7.358±0.167	10.059±0.293	10.646±0.299	11.007±0.361
TVL (cm)	9.434±0.213	19.335±0.996	19.308±0.743	20.460±0.501	20.245±0.961	24.443±0.555	33.415±0.972	35.364±0.993	36.563±1.200

Table 3. continue

Sample No	^{133}Ba (keV)					^{137}Cs (keV)	^{60}Co (keV)	^{22}Na (keV)	^{60}Co (keV)
	81	**276**	**302**	**356**	**383**	**662**	**1173**	**1274**	**1332**
S7									
μ_l (cm^{-1})	0.239±0.005	0.114±0.006	0.121±0.005	0.112±0.003	0.118±0.006	0.090±0.002	0.067±0.002	0.066±0.002	0.062±0.002
μ_m(cm^2/g)	0.166±0.004	0.080±0.004	0.084±0.003	0.078±0.002	0.083±0.004	0.063±0.001	0.047±0.001	0.046±0.001	0.043±0.001
HVL (cm)	2.906±0.065	6.067±0.319	5.749±0.220	6.195±0.152	5.853±0.272	7.706±0.177	10.356±0.305	10.538±0.294	11.252±0.374
TVL (cm)	9.653±0.217	20.154±1.059	19.099±0.730	20.579±0.503	19.445±0.905	25.600±0.588	34.402±1.013	35.008±0.977	37.377±1.243
S8									
μ_l (cm^{-1})	0.256±0.006	0.134±0.007	0.125±0.005	0.123±0.003	0.125±0.006	0.099±0.002	0.074±0.002	0.068±0.002	0.069±0.002
μ_m(cm^2/g)	0.162±0.004	0.085±0.004	0.079±0.002	0.078±0.002	0.079±0.004	0.062±0.001	0.047±0.001	0.043±0.001	0.043±0.001
HVL (cm)	2.704±0.061	5.168±0.251	5.550±0.207	5.639±0.134	5.551±0.250	7.020±0.157	9.338±0.261	10.177±0.278	10.101±0.331
TVL (cm)	8.981±0.201	17.166±0.832	18.435±0.687	18.734±0.444	18.441±0.831	23.319±0.522	31.022±0.867	33.807±0.925	33.555±1.100
S9									
μ_l (cm^{-1})	0.254±0.006	0.135±0.007	0.128±0.005	0.117±0.003	0.115±0.005	0.093±0.002	0.069±0.002	0.065±0.002	0.062±0.002
μ_m(cm^2/g)	0.161±0.004	0.086±0.004	0.081±0.002	0.074±0.002	0.073±0.003	0.059±0.001	0.044±0.001	0.041±0.001	0.039±0.001
HVL (cm)	2.728±0.061	5.116±0.251	5.411±0.202	5.926±0.145	6.052±0.286	7.446±0.169	10.004±0.289	10.732±0.302	11.143±0.369
TVL (cm)	9.061±0.204	16.994±0.834	17.976±0.672	19.685±0.481	20.105±0.951	24.736±0.563	33.231±0.960	35.650±1.003	37.017±1.224
S10									
μ_l (cm^{-1})	0.265±0.006	0.134±0.007	0.132±0.005	0.120±0.003	0.134±0.006	0.093±0.002	0.071±0.002	0.066±0.002	0.065±0.002
μ_m(cm^2/g)	0.164±0.004	0.083±0.004	0.082±0.002	0.074±0.002	0.083±0.004	0.058±0.001	0.044±0.001	0.041±0.001	0.040±0.001
HVL (cm)	2.611±0.059	5.168±0.254	5.257±0.195	5.774±0.139	5.161±0.229	7.449±0.169	9.705±0.277	10.461±0.289	10.620±0.349
TVL (cm)	8.673±0.195	17.166±0.843	17.462±0.646	19.181±0.461	17.145±0.760	24.745±0.563	32.241±0.920	34.752±0.962	35.280±1.158
S11									
μ_l (cm^{-1})	0.267±0.006	0.139±0.007	0.130±0.005	0.124±0.003	0.131±0.006	0.097±0.002	0.073±0.002	0.067±0.002	0.066±0.002
μ_m(cm^2/g)	0.164±0.004	0.085±0.004	0.080±0.002	0.076±0.002	0.080±0.004	0.059±0.001	0.045±0.001	0.041±0.001	0.040±0.001
HVL (cm)	2.598±0.058	5.000±0.241	5.317±0.200	5.582±0.133	5.309±0.236	7.149±0.161	9.449±0.266	10.285±0.283	10.533±0.346
TVL (cm)	8.629±0.194	16.611±0.802	17.664±0.665	18.542±0.443	17.635±0.783	23.750±0.535	31.387±0.883	34.167±0.939	34.991±1.151

Table 4. Mass attenuation coefficients (MACs) of NaCl compound

Energy	^{133}Ba (keV)					^{137}Cs (keV)	^{60}Co (keV)	^{22}Na (keV)	^{60}Co (keV)
	81	**276**	**302**	**356**	**383**	**662**	**1173**	**1274**	**1332**
μ_m(cm^2/g)	0.234	0.108	0.104	0.097	0.094	0.074	0.056	0.054	0.053

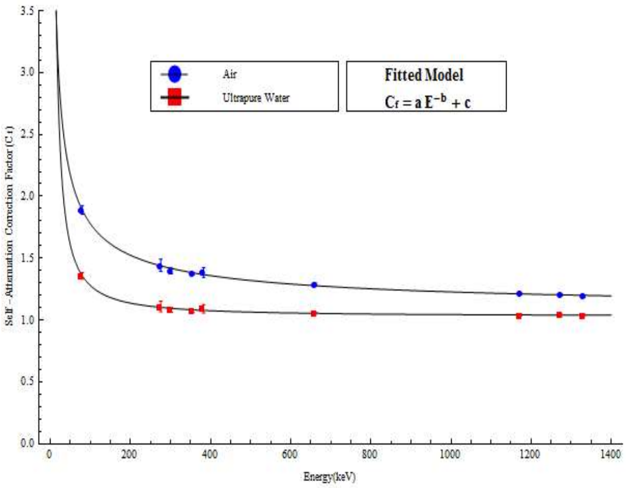

Figure 1. Self-attenuation correction factors of sample 4 versus energy referring to ultrapure water and air

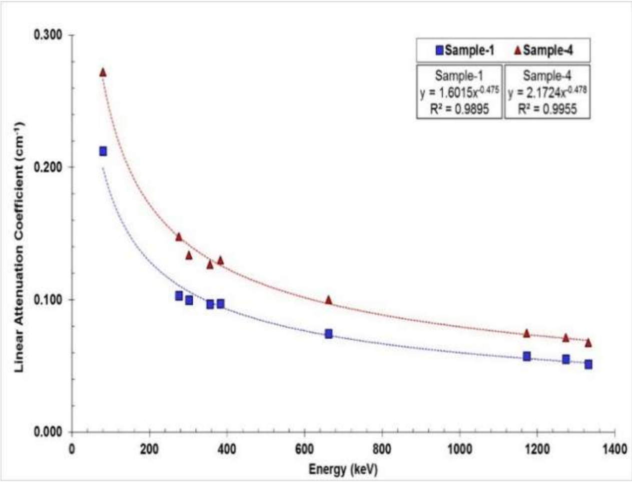

Figure 2. Variation of the LACs of sample-1 and sample-4 as functions of the γ-ray energy

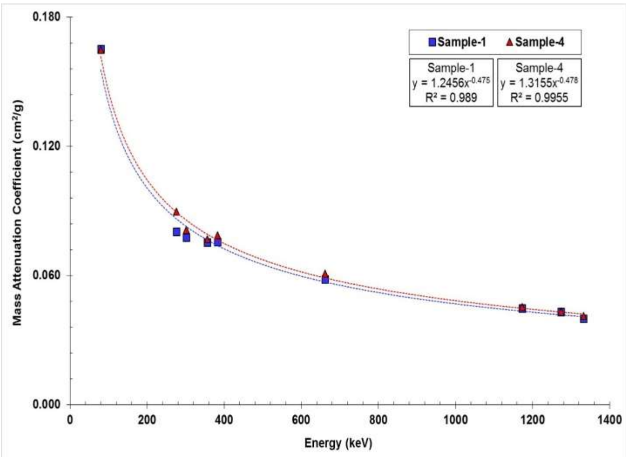

Figure 3. Variation of the MACs of sample-1 and sample-4 as functions of the γ-ray energy

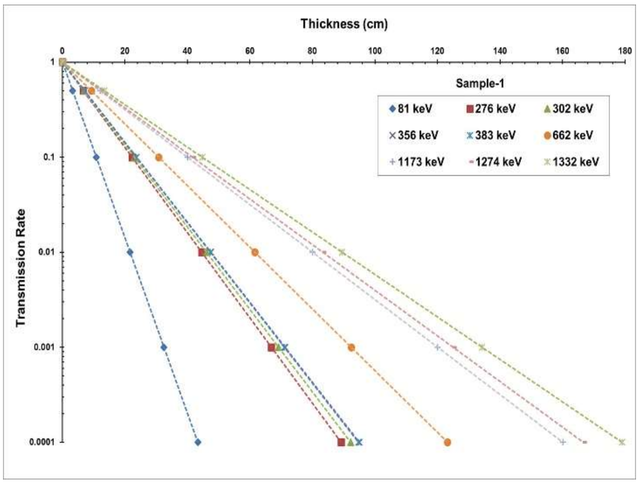

Figure 4. Transmission rate of the sample-1 at different γ-ray energies

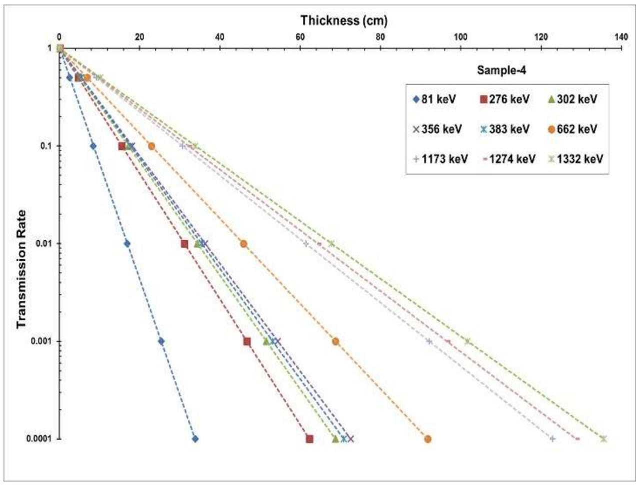

Figure 5. Transmission rate of the sample-4 at different γ-ray energies

4. CONCLUSIONS

The self-attenuation correction factors, LACs, MACs, HVLs and TVLs were calculated experimentally by gamma ray spectrometry between 81 and 1332 keV. The self-attenuation correction factor of salt samples referring to air is higher than that referring to ultrapure water. There are differences between obtained experimental MACs of salts and the results of MACs of NaCl compound obtained from WinXCom software [40]. The LACs are different values for each salt samples whereas the MACs are same values at certain energy for all samples. The HVL and TVL increase with increasing incident gamma-ray energy. The transmission rate decrease with increasing thickness of sample at certain gamma-ray energy.

The self -attenuation coefficient is significant to accurate and reliable activity concentration of the samples. The attenuation coefficients are needed for different applications of radiation, e.g. dosimetry, radiography, tomography in industrial, agricultural and medical areas in science, technology, human health etc. [18, 20, 33]. The results of this study give information about self-attenuation correction factors, LACs, MACs, HVLs and TVLs of salt samples. Chemical components and physical properties of salt samples can be investigated using atomic and nuclear techniques the effect on attenuation coefficients in the future.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Christian Segebade for useful suggestions and comments.

5. REFERENCES

[1] D. Millsap and S. Landsberger, "Self-attenuation as a function of gamma ray energy in naturally occurring radioactive material in the oil and gas industry," Applied Radiation and Isotopes, vol. 97, pp. 21-23, 2015.

[2] P. Jodłowski, P. Wachniew and C. Dinh, "Monte Carlo validation of the self-attenuation correction determination with the Cutshall transmission method in 210Pb measurements by gamma-spectrometry," Applied Radiation and Isotopes, vol. 87, pp. 387-389, 2014.

[3] M. Barrera, A. Suarez-Llorens, M. Casas-Ruiz, J. Alonso and J. Vidal, "Theoretical determination of gamma spectrometry systems efficiency based on probability functions. Application to self-attenuation correction factors," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 854, pp. 31-39, 2017.

[4] N. Cutshall, I. Larsen and C. Olsen, "Direct analysis of Pb-210 in sediment samples: a self-absorption corrections," Nuclear Instruments and Methods in Physics Research, vol. 206, no. 309-312, 1983.

[5] P. Sabyasachi, C. Agarwal, A. Goswami and M. Gathibandhe, "Attenuation correction for the collimated gamma ray assay of cylindrical samples," Applied Radiation and Isotopes, vol. 98, pp. 23-28, 2015.

[6] P. Jodłowski, "A revision factor to the Cutshall self-attenuation correction in ^{210}Pb gamma spectrometry measurements," Applied Radiation and Isotopes, vol. 109, pp. 566-569, 2016.

[7] S. Landsberger, C. Brabec, B. Canion, J. Hashem, C. Lu, D. Millsap and G. George, "Determination of ^{226}Ra, ^{228}Ra and ^{210}Pb in NORM products from oil and gas exploration: Problems in activity underestimation due to the presence of metals and self-absorption of photons," Journal of Environmental Radioactivity, vol. 125, pp. 23-26, 2013.

[8] M. Bonczyk, B. Michalik and I. Chmielewska, "The self-absorption correction factors for ^{210}Pb concentration in mining waste and influence on environmental radiation risk assessment," Isotopes in Environmental and Health Studies, vol. 53, pp. 104-110, 2017.

[9] N. Tsoulfanidis, Measurement and Detection of Radiation (Second Edition), United States of America: Taylor&Francis, 1995.

[10] G. Knoll, Radiation Detection and Measurement (Third Edition), United States of America: John Wiley&Sons, Inc., 2000.

[11] G. Gilmore, Practical Gamma-ray Spectrometry (Second Edition), England: John Wiley&Sons, Ltd, 2008.

[12] S. Ahmed, Physics and engineering of radiation detection, UK: Academic Press Inc. Published by Elsevier, 2007.

[13] C. Laxman and R. Dayanand, "Attenuation Coefficient of Soil Samples by Gamma ray Energy," Research Journal of Recent Sciences, vol. 1, no. 9, pp. 41-48, 2012.

[14] L. Chaudhari, "Attenuation coefficient of cane sugar of milk samples using gamma source," Scholarly Research Journal for Interdisciplinary Studies, vol. 3, no. 20, pp. 1088-1092, 2015.

[15] C. Udagani and T. Ramesh, "Detection and quantitative determination of diethylene glycol in ethyl alcohol using gamma- ray spectroscopy," Journal of Food Science and Technology, vol. 52, no. 8, pp. 5311-5316, 2015.

[16] U. Dindore, S. Rajmane, S. Dongarge and U. Biradar, "Measurement technique of linear and mass attenuation coefficient of naphthalene soluble in ethanol by gamma ray energy at 1.33 M eV," International Journal of Engineering Technology, Management and Applied Sciences, vol. 4, no. 3, pp. 88-93, 2016.

[17] P. Malwadkar and S. Dongarge, "Linear attenuation coefficient of water soluble suger ($C_6H_{12}O_6$) at 0.662 MeV gamma energy by varying concentration," International Journal of Engineering Technology Science and Research, vol. 3, no. 3, pp. 158-162, 2016.

[18] C. Udagani, "Dependence of gamma ray attenuation on concentration of manganese (II) chloride solution," International Journal of Scientific&Technology Research, vol. 2, no. 7, pp. 55-59, 2013.

[19] L. Chaudhari and M. Teli, "Linear attenuation (or absorption) coefficient of gamma radiation for dilute solutions of potassium chloride," Applied Radiation and Isotopes, vol. 47, no. 3, pp. 365-367, 1996.

[20] S. Dongarge, P. Wadkar and M. Teli, "Measurement of linear attenuation coefficients of gamma rays for ammonium sulfate salt by aqueous solution method," International Journal of Physics and Applications, vol. 2, no. 1, pp. 1-8, 2010.

[21] L. Gerward, "On the attenuation of X-rays and gamma-rays in dilute solutions," Radiation Physics and Chemistry, vol. 48, no. 6, pp. 697-699, 1996.

[22] M. Dumpala and A. Nageswara Rao, "Mass attenuation coefficients of lead nitrate dilute solutions for 13.5 cm thickness at 1173 and 1333 keV," International Journal of Innovative Research in Science, Engineering and Technology, vol. 5, no. 5, pp. 8266-8271, 2016.

[23] M. Teli, "On the attenuation of X-rays and γ-rays for aqueous solutions of salts," Radiation Physics and Chemistry, vol. 53, pp. 593-595, 1998.

[24] M. Teli, C. Mahajan and R. Nathuram, "Measurement of mass and linear attenuation coefficients of gamma-rays for various elements through aqueous solution of salts," Indian Journal of Pure & Applied Physics, vol. 39, pp. 816-824, 2001.

[25] D. Gaikwada, P. Pawar and T. Selvam, "Mass attenuation coefficients and effective atomic numbers of biological compounds for gamma ray interactions," Radiation Physics and Chemistry, vol. 138, pp. 75-80, 2017.

[26] P. Kore and P. Pawar, "Measurements of mass attenuation coefficient, effective atomic number and electron density of some amino acids," Radiation Physics and Chemistry, vol. 98, pp. 86-91, 2014.

[27] S. Dongarge and S. Mitkar, "Measurement of linear and mass attenuation coefficient of alcohol soluable compound for gamma-rays at energy 0.36 MeV," Journal of

Chemical and Pharmaceutical Research, vol. 4, no. 6, pp. 3116-3120, 2012.

[28] S. Mitkar and S. Dongarge, "Measurement of linear and mass attenuation coefficient of alcohol soluble compound for gamma rays at energy 0.511 MeV," Archives of Applied Science Research, vol. 4, no. 4, pp. 1748-1752, 2012.

[29] R. Morabad and B. Kerur, "Mass attenuation coefficients of X-rays in different medicinal plants," Applied Radiation and Isotopes, vol. 68, pp. 271-274, 2010.

[30] S. Teerthe and B. Kerur, "X-Ray mass attenuation coefficient of medicinal plant using different energies 32.890 keV to 13.596 keV," Materials Today: Proceedings, vol. 3, pp. 3925-3929, 2016.

[31] B. Saritha and A. Nageswara, "A study on photon attenuation coefficients of different wood materials with different densities," Journal of Physics: Conference Series, vol. 662, p. 012030, 2015.

[32] K. Satoh, N. Ohashi, H. Higuchi and M. Noguchi, "Determination of attenuation coefficient for self-absorption correction in routine gamma ray spectrometry of environmental bulk sample," Journal of Radioanalytical and Nuclear Chemistry, vol. 84, no. 2, pp. 431-440, 1984.

[33] V. Trunova, A. Sidorina and V. Kriventsov, "Measurement of X-ray mass attenuation coefficients in biological and geological samples in the energy range of 7-12 keV," Applied Radiation and Isotopes, vol. 95, pp. 48-52, 2015.

[34] Maestro-32: Multi-channel analyser software, A65-B32 model, Ortec, 2008. [Online].Available: https://www.ortec-online.com/-/media/ametekortec/manuals/a65-mnl.pdf [Accessed 01 Feb 2018].

[35] E. San Miguel, J. Perez-Moreno, J. Bolivar, R. Garcia-Tenorio and J. Martin, "^{210}Pb determination by gamma spectrometry in voluminal samples (cylindrical geometry)," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 493, pp. 111-120, 2002.

[36] Wolfram Research, Inc., Mathematica, Version 8, Champaign, IL, 2010.

[37] M.T. Teli, L.M. Chaudhari, S.S. Malode, "Attenuation Coefficient of 123 keV γ-radiation by dilute solutions of sodium chloride," Applied Radiation and Isotopes, vol.45 (10), pp. 987-990, 1994.

[38] L. Gerward, "Comments on attenuation coefficient of 123 keV γ-radiation by dilute solutions of sodium chloride," Applied Radiation and Isotopes, vol. 47, pp.1149-1150, 1996.

[39] H. Duggal, A. Bhalla, S. Kumar, J.S. Shani, D. Mehta, "Elemental analysis of condiments, food additives and edible salts using X-ray fluorescence technique," International Journal of Pharmaceutical Sciences Review and Research, vol.35, no,2, pp.126-133, 2015.

[40] L. Gerward, N. Guilbert, K.B. Jenden, H. Levring, "WinXCom—a program for calculating X-ray attenuation coefficients, "Radiation Physics and Chemistry, vol.71, pp.653-654, 2004.

[41] M.E. Medhat, V.P. Singh, "Mass attenuation coefficients of composite materials by Geant4, XCOM and experimental data: comparative study," Radiation Effects and Defects in Solids, vol. 169, no. 9, pp. 800-807, 2014.