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Determination of Radionuclide Concentration in Human Teeth in Najaf Governorate, Iraq

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ABSTRACT

Introduction: ^{238}U decays with alpha particles emission into ^{234}Th and the series ends with ^{206}Pb. The unstable nucleus loses the energy with emitting ionizing alpha particles for reaching a stable state. It is undergoing alpha decay with decay energy (4.679 MeV). Alpha particles enter the human and animal bodies through inhalation of air or ingestion of contaminated food and water. This study aimed to perform a radiological analysis on the natural alpha particle emission rates of the human teeth as the biomarkers of radiation exposure and environmental pollution.
Materials and Methods: This study was conducted on 68 teeth samples of 27 males and 41 females collected from the hospitals distributed across Najaf governorate, including many districts in Iraq. Alpha particle emission rates were measured using CR-39 nuclear track detector.
Results: The mean emission rate of alpha particles in the female teeth was 0.0396±0.0070 mBq cm^{-2}, which was relatively higher than that in the male teeth (0.0390±0.0048 mBq cm^{-2}). Nevertheless, there was no significant difference between the female and male teeth regarding the emission rate of alpha particles. Furthermore, the emission rate of alpha particles in the teeth of the samples taken from Kufa (0.0417±0.0057 mBq cm^{-2}) was higher than those obtained from Najaf (0.0384±0.0053 mBq cm^{-2}).
Conclusion: As the findings of this study revealed, Najaf governorate had a lower emission rate of alpha particles as compared to other sites of the worldwide. Therefore, it could be concluded that there is no negative consequence threatening the people's health in this regard.

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Introduction

Uranium, which can be found everywhere on the Earth, is used as the fuel for a nuclear reactors and weapons. Natural uranium consists of about three isotopes, namely uranium-238 (^{238}U), uranium-235 (^{235}U), anduranium-234 (^{234}U). The nuclei of radioactive substances are transformed into other elements either emitting or absorbing particles. ^{238}U decays into ^{234}Th with the alpha particle emission [1]. After alpha decays, the series end with ^{206}Pb.

The decay chain of 235U is known as the 'Actinium Series' with ^{234}Th being the next isotope in this decay process. The unstable nucleus is loses the energy by the emission of ionizing alpha particles for reaching a stable state with the decay energy of 4.679 MeV [2]. This radioactive substance can enter the human and animal bodies through the inhalation of air or ingestion of contaminated food and water [3].

Harrison et al. (2007) explained the mechanism through which the alpha particles emitted by ^{210}Po cause damage within the body [4]. Ionizing radiations, including alpha particles, can kill the cells damaging the biological molecules within them, including DNA. Alpha particle activity is 10-15 times higher in the teeth than that in other body organs.

The studies on autopsy tissue have mainly focused on determining the principal alpha emitters, namely ^{210}Po, ^{226}Ra, and ^{238}U. These nuclei are found in human tissues with the activity values of 1.0-3.0mBq g^{-1}, 0.2-0.3 mBq g^{-1}, and 0.05 mBq g^{-1}, respectively [5].The amount of radionuclides accumulated in the human body depend on the transfer rates of the radionuclide from the environment (i.e., air, soil, and water) to the human body. There are several studies investigating the alpha emission in biological samples using track detector due to thier high resolution and ability to detect very low concentration.

The ^{238}U and ^{230}Th have similar distributions in the bones with rather lower concentrations than ^{232}Th. These radioisotopes chemically and physiologically behave like Ca and tend to be concentrated in the bone and tooth [6]. The ^{226}Ra is expected to be present in the bone since it tends to be moderately transferable in the physical environment. The ^{226}Ra is taken up by the plants and assimilated efficiently from the gut when ingested by the animals [7].With this background in mind, the present study aimed to

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assess the uptake of alpha radioactivity in human teeth and determine how alpha levels could be used as the biomarkers of exposure to natural radioactivity in Najaf Governorate, Iraq.

Materials and Methods

This study was conducted on 68 teeth samples of 27 males and 41 females within the age range of 13-60 years, which were collected from the hospitals distributed across the Najaf governorate, including many districts (Figure 1).

Najaf Province is a governorate in the southwestern region of Iraq. The capital city of this province is Najaf (area: 28,824 km, population: 1,220,145) (Figure 1). All samples were permanent teeth without any fillings. The teeth samples were prepared as described in a study conducted by Henshaw et al. (1994) [9] and sealed in vials and sterilized in 10% formaldehyde solution (Figure 2).

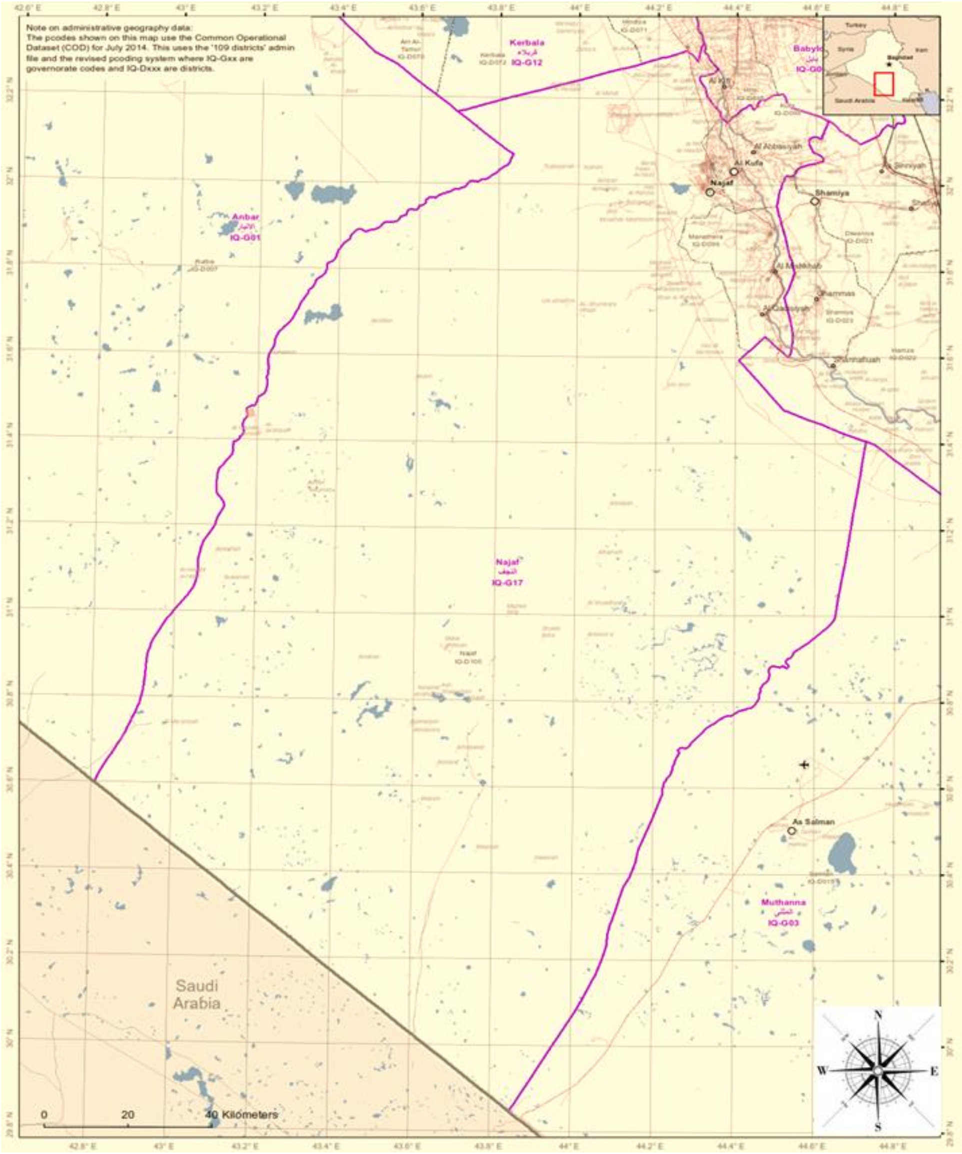

Figure 1. Administrative map of Najaf governorate [8]

The alpha emission rate in the teeth samples was determined using an alpha-sensitive detector (PADCTASTRACK CR-39, Track Analysis Systems Ltd, UK). The CR-39 nuclear track detector has a high sensitivity to record the tracks of proton, alpha particle, and fission fragments since it contains the bonds of weak carbon that easily breaks when exposed to radiation. The teeth samples were collected by the nursing staff, who recorded such information as gender, age, town, and smoking status on each tooth sample.

Figure 2. Sealing teeth samples in vials with formaldehyde solution

The tooth samples were cleaned of soft tissue and organic material, washed with distilled water, and dried at a temperature of 100°C for 2 h using an oven.

The teeth selected for the assay of the alpha emission rates were sliced into two longitudinal sections using a Marathon Micromotor System (Beijing China Skysea Business Co.Ltd, Korea) with a diamond disk with a diameter of 2 mm (Figure 3).

Figure 3. Marathon Micromotor System

The CR-39 detector (TASTRAK α-particle-sensitive with about a 2×2 cm^2) was placed between two teeth halves using the adhesive tape. As shown in Figure 4, the detector along with sample was sealed in a high-density polyethylene bag to prevent form the escape of the radon gas.

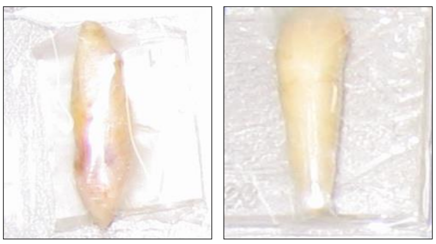

Figure 4. Sealing detector with sample in a high-density polyethylene bag

Subsequently, the bags were placed in a freezer at -20°C for 115 days (to prevent from the escape of radon gas) to allow the alpha tracks emitted from the natural levels of activity in the teeth to accumulate on the TASTRAK detector. In our technique, the alpha particles were measured without the chemical treatment of the teeth samples using CR-39 detector.

After the exposure period, the CR-39 detectors were etched under controlled conditions by NaOH solution as reported previously [10-12]. The number of alpha tracks per unit area for the teeth samples was counted using an optical microscope (A. Kruss Optronic, Germany) with the MDCE-5C camera at 10x magnification.

The CR-39 efficiency in this study was 85%, which was calculated using the following formula [3, 11, 13]:

$$\varepsilon = 1 - \frac{V_B}{V_T}, \quad (1)$$

Where V_B represents bulk etch rate (μm h^{-1}), and V_T signifies track etch rate (μm h^{-1}).

The alpha emission rate (Eα) was calculated using the formula [3, 11, 14]:

$$E_\alpha (Bq\ cm^{-2}) = \varepsilon \% \frac{(\rho_s - \rho_b)}{T}, \quad (2)$$

Where T is exposure time (seconds), ρ_S is the number of tracks produced by the samples (track cm^{-2}), and ρ_b is the number of background tracks.

The analyses of the background track density were performed on a blank plastic CR-39 detectors stored alongside the teeth autoradiographs.

Results

The alpha emission rates in the teeth samples for the two faces of CR-39 detector are illustrated in Table 1. Standard uncertainty represents the uncertainty of the result of a measurement expressed as a standard deviation or a standard error. Standard error was calculated through dividing the standard deviation by the square root of the number of Field of View (FOV) (the number of degrees of visual angle during stable fixation of the eyes, as the magnification increases, the FOV decreases) using the Excel software. In this study, a mean background alpha particle track density of 68.66±4.17 tracks per cm^2 was recorded on the detectors stored for a minimum period of 107 days.

Table 1. Alpha emission rates in the teeth samples

Sample code	Place of residence	Face$_1$	Face$_2$	Mean		
		Track cm^{-2}d^{-1}	Track cm^{-2}d^{-1}	Track cm^{-2}d^{-1}	E_α (mBq cm^{-2})	Standard error
211	Mukarramah	8.807	7.988	8.398	0.083	0.002
292	Kufa	3.662	3.677	3.669	0.036	0.000
316	Kufa	4.246	4.256	4.251	0.042	0.001
289	Mmuamml	7.316	7.283	7.300	0.072	0.001
317	Furat	5.056	8.508	5.031	0.049	0.002
318	Qadisiyah	8.427	5.115	8.468	0.083	0.003
237	Quds	5.097	2.846	5.106	0.050	0.001
236	Alrhmh	2.902	2.074	2.874	0.028	0.001
263	Albrakih	2.076	2.074	2.075	0.020	0.000
190	Albrakih	7.088	0.817	7.074	0.070	0.001
265	Alnasr	0.825	0.825	0.821	0.008	0.000
290	Alsahvir	2.656	2.673	2.664	0.026	0.001
215	Alabasiah	11.845	12.026	11.935	0.117	0.004
320	Alabasiah	11.288	11.447	11.368	0.112	0.004
212	Maddenh Street	4.389	4.379	4.384	0.043	0.001
266	Albrakih	2.103	2.126	2.114	0.021	0.001
241	Albrakih	2.234	2.221	2.228	0.022	0.000
315	Aloroba	1.740	1.715	1.728	0.017	0.000
235	Maysan	7.352	7.350	7.351	0.072	0.001
214	Almhenddsin	9.074	9.013	9.043	0.089	0.002
245	Almhaml Street	2.979	3.031	3.005	0.030	0.001
210	Kufa	1.142	1.183	1.163	0.011	0.001
288	Almelad	11.495	11.303	11.399	0.112	0.003
213	Maysan	7.330	7.222	7.276	0.072	0.001
242	AlJazeera	2.947	2.964	2.956	0.029	0.000
293	Alsahvir	4.169	3.701	3.935	0.039	0.001
217	Almelad	0.940	1.028	0.984	0.010	0.000
313	AlJazeera	9.580	9.353	9.466	0.093	0.001
150	Zahra	9.988	9.785	9.886	0.097	0.002
120	Alwafa	3.883	4.322	4.102	0.040	0.001
118	Alnasr	0.126	0.111	0.119	0.001	0.000
100	Albrakih	0.080	0.079	0.080	0.001	0.000
178	Alneda	16.139	31.035	23.587	0.232	0.005
069	Anasr	4.191	4.164	4.178	0.041	0.001
050	Ansar	0.282	0.260	0.271	0.003	0.000
051	Aljhmaiha	0.398	0.451	0.424	0.004	0.000

Sample code	Place of residence	Face1	Face2	Mean		
		Track $cm^{-2}d^{-1}$	Track $cm^{-2}d^{-1}$	Track $cm^{-2}d^{-1}$	E_{α} (mBq cm^{-2})	Standard error
049	Ansar	0.080	0.080	0.080	0.001	0.000
045	Ansar	11.811	11.850	11.831	0.116	0.002
123	17 Tamuz	2.272	2.252	2.262	0.022	0.000
174	Alrhmh	4.143	4.158	4.151	0.041	0.003
095	Quds	2.288	2.483	2.386	0.023	0.001
093	Aljhmaiha	6.615	6.669	6.642	0.065	0.002
124	Albrakih	1.085	1.105	1.095	0.011	0.000
073	Kufa	0.009	0.016	0.013	0.000	0.000
064	Ghammas	2.189	2.225	2.207	0.022	0.000
071	Alehiarh	2.928	2.921	2.924	0.029	0.000
119	Almhaml Street	2.801	2.808	2.804	0.028	0.001
152	Gas Factory	0.835	0.843	0.839	0.008	0.000
238	17 Tamuz	3.519	3.526	3.522	0.035	0.001
086	Albrakih	9.040	9.105	9.073	0.089	0.003
092	Albrakih	0.781	1.313	1.047	0.010	0.001
144	Ansar	0.551	0.546	0.549	0.005	0.000
097	Karbala Street	3.660	3.699	3.679	0.036	0.001
047	Ansar	2.176	2.128	2.152	0.021	0.001
091	Albrakih	2.558	2.526	2.542	0.025	0.001
147	Imam Mahdy	5.652	5.868	5.760	0.057	0.001
096	Aalaskari	3.778	3.713	3.745	0.037	0.001
145	Mutanabi	3.481	3.546	3.514	0.035	0.001
099	Aljammeha	0.250	0.259	0.254	0.003	0.000
169	Almilahd	0.084	0.091	0.088	0.001	0.000
148	Aljhmhoriha	2.395	2.386	2.390	0.024	0.001
151	Nasr	1.882	1.875	1.878	0.018	0.001
122	Ansar	4.177	4.152	4.165	0.041	0.001
125	Alsahvir	1.144	1.135	1.140	0.011	0.001
121	Kufa	4.489	4.109	4.299	0.042	0.002
066	Aladalh	11.754	11.804	11.779	0.116	0.002
146	Gamaah	1.527	1.515	1.521	0.015	0.000
072	Kinda	2.071	2.102	2.087	0.021	0.001
070	Mukarramah	3.013	2.995	3.004	0.030	0.001
098	Kufa	2.956	2.970	2.963	0.029	0.001
067	Kufa	3.779	3.874	3.826	0.038	0.002
	Mean	**4.164**	**4.240**	**4.266**	**0.042**	**±0.001**

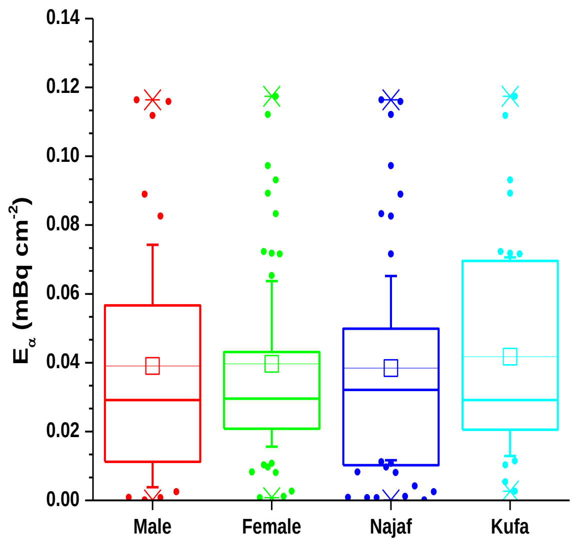

Figure 5. Distribution and variability of alpha emission rate in teeth samples in terms of gender and sampling sites

Table 2. Analysis of alpha emission rate (mBq cm^{-2}) for all samples

	Sum of squares	Degree of freedom	Mean square	F	Sig
Between groups	11081435.853	71	156076.561	1156.225	0.0001
Within groups	10466566.690	77537	134.988		
Total	21548002.544	77608			

The mean emission rate of alpha particles in the female teeth was 0.0396±0.0070 mBq cm^{-2}, which was slightly higher than that in the male teeth (0.0390±0.0048 mBq cm^{-2}) (Figure 6). However, this difference was not statistically significant (P>0.05). The box plot in Figure 6 presents the statistical analysis of the data, variability, and distribution of the emission rate of alpha particles according to the gender and sampling sites. The whiskers extend to the most extreme data points, which are not considered outliers [15].

All samples have outliers and extreme values, which affect the mean value and standard deviation. With regard to the sampling sites, the comparison between Najaf and Kufa was plotted for the teeth samples in Iraq. As shown in Figure 6, the alpha rate was slightly higher in the teeth samples collected from Kufa (0.0417±0.0057 mBq cm^{-2}) than those obtained from Najaf (0.0384±0.0053 mBq cm^{-2}). However, this difference was not statistically significant (P>0.05).

To summarize the results of the estimated alpha emission rate, a box plot graph was used to evaluate the distribution of the calculated results (Figure 5). This methodology allows determining the mean, median, and dispersion of the results. The statistical analysis results (ANOVA) were obtained using the SPSS version 20.0.

According to Table 2, there was a statistically significant difference between alpha particle tracks in all teeth samples, this indicated that the alpha particles had different effects on people's health.

Table 3 shows the mean values of alpha emission rate and the 95% confidence interval for the mean of each sample.

Table 3. Descriptive and inferential statistics of the alpha emission rates of the study samples

SC	Mean	SD	Standard error	95% Confidence interval for mean		Minimum	Maximum
				lower bound	Upper bound		
211	26.3646	17.5737	.5352	25.3143	27.4148	3.00	86.00
292	12.2273	4.5129	.1374	11.9576	12.4970	5.00	21.00
316	13.9666	7.0569	.2149	13.5449	14.3883	4.00	31.00
289	23.0816	6.5666	.2000	22.6892	23.4741	9.00	35.00
317	16.2996	13.3838	.4076	15.4998	17.0995	4.00	48.00
318	26.5742	18.9325	.5766	25.4428	27.7057	5.00	69.00
237	16.5223	6.8529	.2087	16.1127	16.9318	8.00	33.00
236	9.8479	4.8151	.1466	9.5601	10.1356	4.00	18.00
263	7.4610	2.3425	.0713	7.3210	7.6010	3.00	11.00
190	22.4072	9.5969	.2923	21.8337	22.9808	7.00	48.00
265	3.7106	4.0724	.1240	3.4672	3.9540	1.00	19.00
290	9.2217	9.1469	.2785	8.6751	9.7683	1.00	37.00
215	36.9425	31.4364	.9574	35.0638	38.8212	19.00	201.00
320	35.2449	27.6584	.8424	33.5920	36.8978	19.00	201.00
212	14.3636	8.3335	.2538	13.8656	14.8617	5.00	37.00
266	7.5779	8.3866	.2554	7.0767	8.0791	1.00	31.00
241	7.9165	3.5530	.1082	7.7042	8.1289	2.00	19.00
315	6.4212	3.7330	.1137	6.1981	6.6442	1.00	13.00
235	23.2347	9.4839	.2888	22.6679	23.8015	5.00	41.00
214	28.2950	15.0630	.4587	27.3948	29.1952	12.00	59.00
245	10.2412	8.7326	.2659	9.7193	10.7631	1.00	28.00
210	4.7319	5.2371	.1595	4.4189	5.0449	2.00	21.00
288	35.3386	19.4872	.5935	34.1740	36.5032	9.00	71.00
213	23.0111	9.4623	.2882	22.4456	23.5766	5.00	41.00
217	4.1976	2.4839	.0756	4.0491	4.3460	1.00	10.00
313	29.5603	8.9453	.2724	29.0257	30.0949	12.00	47.00
150	30.8163	13.4390	.4093	30.0132	31.6195	8.00	62.00
120	13.5213	10.3907	.3164	12.9004	14.1423	2.00	49.00
118	1.6164	1.3158	.0401	1.5376	1.6952	.00	4.00
100	1.4935	1.1185	.0340	1.4267	1.5604	.00	3.00
069	13.7468	7.0892	.2159	13.3231	14.1704	4.00	29.00
050	2.0659	1.5538	.0473	1.9730	2.1587	.00	4.00
051	2.5250	2.5807	.0786	2.3708	2.6793	.00	8.00
049	1.1215	1.0525	.0320	1.0586	1.1844	.00	3.00
045	36.6299	18.2583	.5561	35.5387	37.7210	18.00	72.00
123	8.0195	3.0058	.0915	7.8398	8.1991	4.00	14.00
174	13.6660	25.2213	.7681	12.1588	15.1733	1.00	116.00
095	9.4643	8.6433	.2518	8.9703	9.9584	1.00	46.00
093	21.1196	13.4907	.4313	20.2731	21.9662	2.00	46.00
124	4.5306	3.9707	.1209	4.2933	4.7679	1.00	15.00
073	1.2941	1.5821	.0481	1.1995	1.3886	.00	4.00
064	7.8534	3.2148	.0979	7.6613	8.0456	.00	14.00
071	9.9991	3.5023	.1066	9.7898	10.2084	5.00	16.00
119	9.6410	6.2769	.1911	9.2659	10.0161	1.00	23.00
152	3.7644	2.8000	.0852	3.5970	3.9317	.00	8.00
238	11.7876	5.9179	.1802	11.4339	12.1412	2.00	23.00
086	28.3831	24.2633	.7389	26.9331	29.8331	4.00	96.00
092	4.3868	5.3456	.1628	4.0674	4.7063	1.00	48.00
144	2.8961	1.3757	.0419	2.8139	2.9783	1.00	6.00
097	12.2570	4.6917	.1429	11.9766	12.5373	2.00	21.00
047	7.6902	8.4238	.2565	7.1867	8.1936	1.00	31.00
091	8.8562	7.8655	.2395	8.3862	9.3263	.00	23.00
147	18.3825	11.0081	.3322	17.7307	19.0344	4.00	42.00
096	12.4395	7.1231	.2189	12.0098	12.8692	4.00	33.00
145	11.7616	7.0555	.2148	11.3399	12.1833	3.00	29.00

SC	Mean	SD	Standard error	95% Confidence interval for mean		Minimum	Maximum
				lower bound	Upper bound		
099	2.0158	1.4417	.0439	1.9296	2.1019	.00	9.00
169	1.5176	1.1242	.0342	1.4504	1.5848	.00	3.00
148	8.4026	5.8345	.1777	8.0539	8.7513	1.00	21.00
151	6.8720	7.0688	.2153	6.4495	7.2944	.00	21.00
122	13.7078	7.0909	.2159	13.2840	14.1316	3.00	27.00
125	4.6633	5.6953	.1734	4.3229	5.0036	.00	24.00
121	14.8758	13.6783	.4103	14.0706	15.6810	1.00	72.00
066	36.4722	18.2553	.5655	35.3625	37.5819	18.00	72.00
146	5.8033	3.8517	.1173	5.5732	6.0335	2.00	17.00
072	7.4954	6.8153	.2075	7.0881	7.9027	.00	26.00
070	10.2365	4.6407	.1413	9.9592	10.5139	3.00	21.00
098	10.1150	5.3922	.1642	9.7928	10.4373	2.00	21.00
067	12.6967	11.7575	.3581	11.9940	13.3993	1.00	37.00
Total	13.8209	16.6628	0.0598	13.7037	13.9382	0.00	201.00

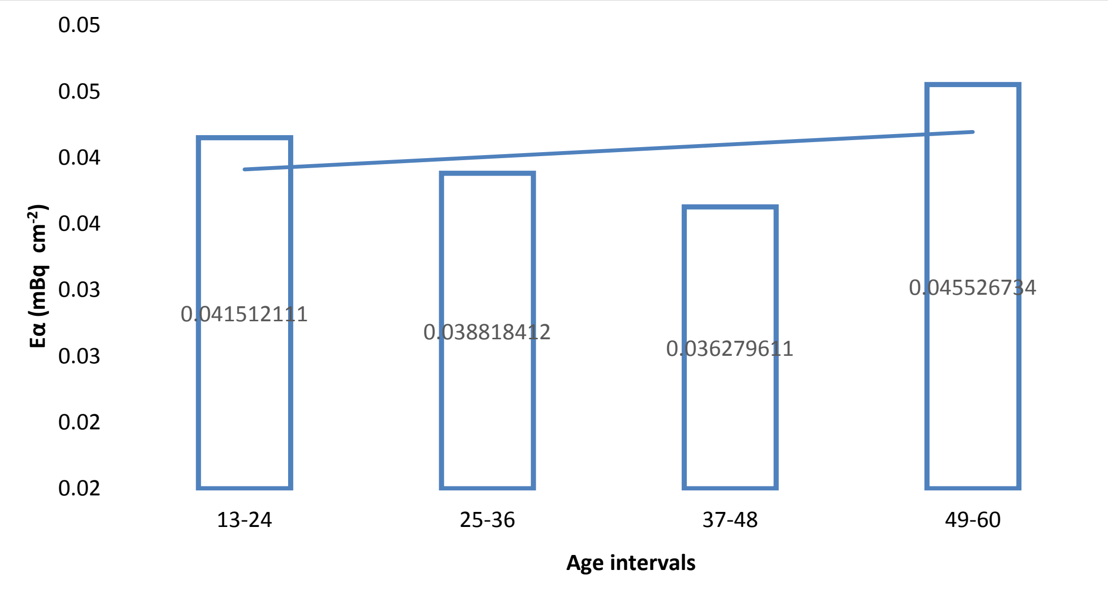

Figure 6. Relationship of alpha emission rate and age groups based on standard error

A total of 73,304 track readings of the teeth were obtained using a CR-39 detector. The effect of the donor's age (13-24, 25-36, 37-48, and 49-60 years) on the alpha emission is displayed in Figure 6. The alpha emission rates were found to be high (0.0690 m Bq cm^{-2}) and low (0.0406 m Bq cm^{-2}) at the age ranges of 49-60 and 37-48 years, respectively, which was indicative that alpha radionuclides have different effect with the age.

Discussion

There are certain tissues in animal and human beings tending to accumulate selected radionuclides. Radium is distributed in the organism after oral exposure. This element decreases the tissue content in blood, and later appears in the urine and feces. Retention in tissues decreases with the time following maximal uptake after the intake to the blood. The bones and teeth are the principal ^{226}Ra repository in the body due to having the same chemical and physiological behavior as calcium [6]. The radionuclides present in an animal's diet are probably absorbed from the gastrointestinal tract into the blood [16].

Some organs and tissues, notably bones, have the capacity to concentrate ^{226}Ra from blood. Although some of the ^{226}Ra are excreted through the feces and urine over a long time, a portion will remain in the bone throughout the organism's lifetime. The International Commission on Radiological Protection considers that radium removal from the bone volume to blood occurs very slowly during organism life, having a biological half-life of 1200 days [16].

In a study conducted in Malaysia, Almayahi et al. (2012) found the alpha emission rate of 0.0515 mBq cm^{-2} in the animals' bones using CR-39 [11]. In another study carried out in the UK, Henshaw et al. (1994) showed the uptake and micro-distribution of the alpha particle radioactivity in human teeth using

CR-39. They found the transference of ^{226}Ra in the fetal teeth (2.05 Bq kg $^{-1}$) through systemic blood circulation [9]. The alpha particle rate in the tooth has been measured in some countries using a CR-39. Henshaw et al. (1988) measured the mean ^{210}Po and ^{226}Ra values in human bones in the UK (1.46 Bq kg^{-1} and 0.003 Bq kg^{-1}, respectively) [17]. Henshaw et al. (1989) found the mean ^{226}Ra value of 9 Bq kg^{-1} in the human teeth in the UK [18]. Furthermore, James et al. (2004) demonstrated the accumulation of ^{210}Po on the teeth [19].

The alpha activity was measured in the human teeth (5 Bq kg^{-1}) in the UK. In addition, O'Donnell et al. (1997) measured the plutonium level and total alpha emitters in the human teeth in the UK (5 mBq kg^{-1} and 7 Bq kg^{-1}, respectively) [20]. Furthermore, Bunzl and Kracke (1983) measured the plutonium level (4 mBq kg^{-1}) in the human bones in Germany [21].

In Malaysia, Almayahi et al. (2014) showed the uptake and micro-distribution of the alpha particle radioactivity in the human teeth using CR-39 and found the alpha emission rates of 0.0345 mBq cm^{-2} in the teeth [3], which was relatively similar to the value obtained in the present study (0.0394 mBq cm^{-2}). The variation in alpha particle rates in the teeth samples collected from the study area might depend on the transfer rate of radioactivity from soil, water, air, and food to human.

Conclusion

As the findings of the present study indicated, gender had no considerable effect on the alpha emission rates. Overall, the teeth samples had low alpha activities, which caused no dangerous effects on the human health. These results could be a marker for the transfer rate of radioactivity from soil, water, food, and air to the human and animal. The findings of the present study could be useful in determining the alpha exposure rates of the population within the study area for the radiological protection and prevention of extreme exposure.

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