Chapter

Radon in Foods

Tayseer I. Al-Naggar and Doaa H. Shabaan

Abstract

This chapter show the natural of radioactivity as alpha particle which produce from decaying of radium to radon so in this chapter describe the radon in some types of household food (coffee, tea, powder milk, rice, flour, cornstarch, and powder coconut) and different types of salt by using Solid State Nuclear Track Detectors (SSNTD), were analyzed by closed-can technique (CR-39). Many food items contain natural sources of salt. Salt analysis is very important due to its high consumption by the population and for its medicinal use. Analysis the concentrations of Radon-222 and Radium-226 for different types of household foods samples are very substantial for realizing the comparative contributions of specific substances to the whole radon content set within the human body. After study it is found that the average values of annual effective dose in mSv/y are within the recommended limit of ICRP values except its values for cornstarch and sugar are relatively high, and there are a wide range of variations in the values of transfer factor for Rn-222, and Ra-226 for all types.

Keywords: radon, CR-39, food, radiation hazards, closed can technique

1. Introduction

Uranium occurs naturally in low concentrations (a few parts per million) in soil, rock, surface water, and groundwater. It is a relatively reactive element which combines with non–metals such as oxygen, sulfur, chlorine, fluorine, phosphorus, and bromine [1]. Naturally, Uranium exists as three isotopes ^{234}U, ^{235}U and ^{238}U with a relative abundance of 0.0055, 0.720 and 99.29%, respectively [2]. Uranium and its compounds are carcinogenic and highly toxic, which causes acute kidney failure and death in high concentrations as well as brain, liver and heart diseases [2]. Uranium ore is relatively harmless, as long as it remains outside of the body. Once ingested uranium is highly toxic and attacks the inner organs such as kidneys, lungs and heart. Uranium has been repeatedly claimed to be the cause of cancer, leukemia and other health effects. Health effects from external exposure are limited to skin contact and uranium object would have to stay in direct skin contact for more than 250 h. If this will happen then a person will be susceptible to skin cancer [3].

Uranium daughters (Ra-226 and Rn-222) are mainly have a major health risk. The measurements of radon and radium concentrations in foods are main for the health safety. Radium-226 in the environment is broadly spreading, and usually presented in several concentrations in soils, water, foods, sediments and rocks. However, the chemical manner of radium is as like as calcium, therefore radium absorbed to blood from lungs or gastrointestinal tract (GI-tract) or follows the manner of calcium and is mainly deposited in bone [4]. Radon-222 is a progeny product of radium-226 which is called alpha gas emitter. Its half-life of 3.82 days with alpha energy 5.49 Mev. Radon progenies are Po-218 and Po-214 emit alpha particles. These daughters' yields are hard and have a trend to relate themselves to aerosols in around air. When human respire or inhale radon and its progenies along with the normal air, most of the radon is exhaled, its progenies become record to the internal walls and membranes of our respiratory system and continue producing steady damage because of their alpha activity [5, 6].

Radiation contamination which are existing in water and soil can be transported by the food chain to humans and animals [6, 7]. When the human are eating plants, meat of animals or drinking any fluids (tea, coffee, water, and juice), he can be contaminated with different radioactive isotopes (Ra-226, Rn-222, U-238, etc). Plants contain radioactive isotopes initiating from the soil, that absorbed it with other natural substances. Also drinking water and fluids can contain low dose. Air which human breath it, is the primary source of radioactive dose that enter the human body, and as well as the main source of radon that found in the earth's atmosphere generated by the automatic decomposition of uranium [6, 8]. The breathing of radon radioactive progenies with ambient air can caused kidney infections, lung cancer, and skin.

2. Materials and methods

2.1 The samples

Through current work, 24 samples from different types of household foods were collected from Egyptian markets which these foods are considered the daily diet of Egypt residents. These household foods are (coffee, tea, powder milk, rice, flour, cornstarch, and powder coconut, salt) were analyzed by closed-can technique (CR-39). Fifty grams from each sample was put in plastic can as its natural form without any process, a piece of CR-39 manufactured by TASTRACK. Analysis System, Ltd., UK:TASTRACK, which has dimensions (1 × 1) cm was fixed well in the cover of plastic can in front of the sample, after that CR-39 detector was covered by a piece of sponge to prevent thoron-220 from the arrival to CR-39 detector. Plastic can was closed well by its cover and was left for 1 month as exposure time, closed can techniques produced in **Figure 1**. CR-39 polymer detector registers alpha particles which emitted by decay of radium to radon gas as tracks. After the exposure time, CR-39 detectors were assembled from cans and chemically etched in NaOH solution 6.25 M at 70°C to enlarge and appear the alpha tracks through time equal 8 h [9]. After that, CR-39 detectors were washed by purified water and dried well in air. Numbers of tracks for each detector were counted by an optical microscope at a magnification of 400×. Background of CR-39 detectors were registered in this study and subtracted from the net tracks for each sample.

2.2 Theoretical concepts

The activity concentration of radon (Bq/m^3) can be calculated by using the following equation [10–12]:

$$C = \frac{\rho}{K.T} \tag{1}$$

where k is the calibration factor has unit (Bq/m^{3}d)/(track/cm^2), ρ is track density (number of tracks/cm^2) and T is exposure time (in days). The calibration factor value (0.20 Bq/m^{3}d)/(track/cm^2) as reported at many studies [10–12].

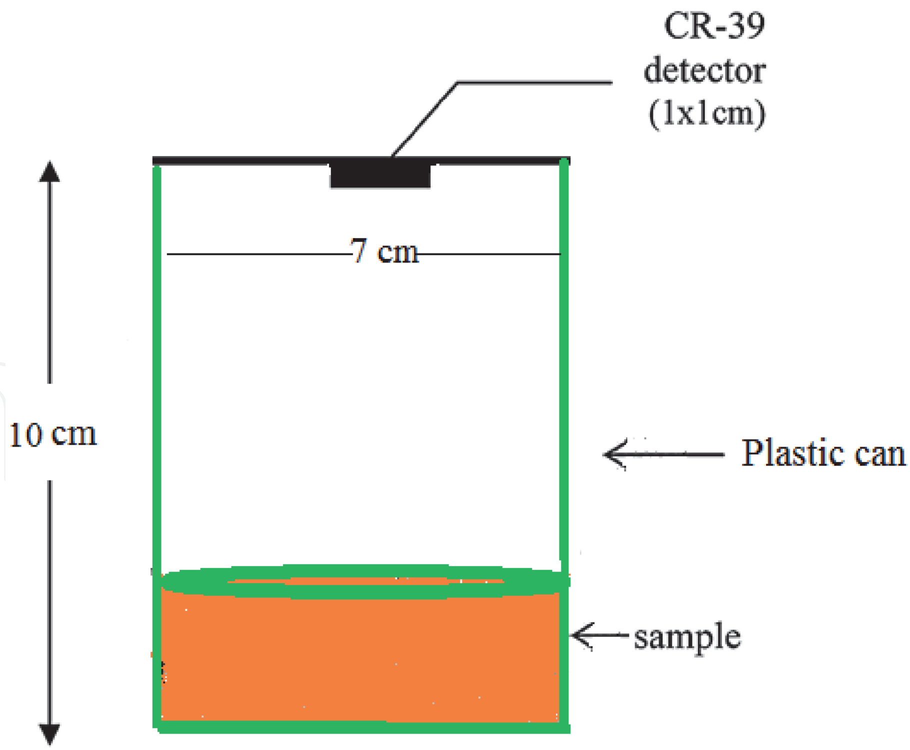

Figure 1.
Closed can technique of CR-39 with household foods samples.

The effective radium content C_{Ra} (Bq/kg) can be found from the equation [1,12]:

$$C_{Ra} = \frac{\rho h A}{k T_e M} \quad (2)$$

where ρ is the counted track density, h is the distance between the detector and the top of the sample, k is the calibration factor of the CR-39 detector, M is the mass of the sample, and T_e is the effective exposure time which can be determined by the following equation.

$$T_e = T - \frac{\left(1 - e^{-\lambda_{Ra} T}\right)}{\lambda_{Rn}} \quad (3)$$

where T is the exposure time, and λ_{Rn} decay constant for radon (h^{-1}).

The radon exhalation rate can be determined from the relation reported by [1, 12]:

$$E = \frac{C_{Rn} \lambda V}{A T_e} \quad (4)$$

where C_{Rn} is radon exposure ($Bqm^{-3}h$), λ_{Rn} decay constant for radon (h^{-1}), A is surface area of water samples (m^2), V is volume of the can (m^3).

The annual effective dose (E_{eff}) (mSv/y) can be obtained using the equation [13]:

$$E_{eff} = C \times F \times H \times T \times D \quad (5)$$

where H is the occupancy factor which is equal to (0.8), T is the time in hours in a year (T = 8760 h/y), and D is the dose conversion factor which is equal to (9×10^{-6} (m Sv)/(Bq h m^{-3})) [14].

Transfer factor (TF) for radionuclides (Rn-222, and Ra-226) in household foods:

Concentrations of radionuclides in foods which are grown in the soil depend on the concentrations of theses radionuclides in dry soils. Transfer factor (TF) can be calculated by the following equation [8, 15, 16]:

$$TF = \frac{C_{foods}\left(Bq\,kg^{-1}dry\ weight\right)}{C_{soil}\left(Bq\,kg^{-1}dry\ weight\right)} \tag{6}$$

where C_{foods} is the activity concentration of ^{226}Ra or ^{222}Rn in dry weight of foods samples and C_{soil} is the average activity concentration of radionuclide (^{226}Ra or ^{222}Rn) in dry weight of soil samples.

3. The concentration of radon

3.1 The radon in salt

The variation of radon concentration with types of salt is shown in **Figure 2**. It is found that the radon concentration in local salt has range between 335.46 and 558.94 Bq m^{-3} with average 447.15 Bq m^{-3}, and in imported salt has range between 223.58 and 335.36 Bq m^{-3} with average 279.47 Bq m^{-3} but in rock salt has range between 484.42 and 633.47 Bq m^{-3} with average 549.63 Bq m^{-3} as showed in (**Table 1**), It is shown that the concentration in rock salt is higher than the recommended value 400 Bq/m^3 [17], but its concentrations lower in the other types may be attributed to the quality of selection processes for samples where rock salt was selected from the bottom of sea and this due to increase in the radon concentration. **Figure 3** shown the annual effective dose from corresponding radon concentration with types of salt it is found that in local salt has range between 7.25 and 12.08 m Sv y^{-1} with average 9.67 m Sv y^{-1} and in imported salt has range between 4.83 and 7.25 m Sv year^{-1} with average 6.04 m Sv year^{-1} but in rock salt has range between 10.47 and 13.69 m Sv year^{-1} with average 11.8775 m Sv year^{-1} which higher than limited value [17], as shown in **Table 1**. These values meet that the results in range with other literature [16]. The radon exhalation rate with samples salt it is found that local salt has range between 0.0011 and 0.0019 Bq m^{-2} h^{-1} with average 0.0015 Bq m^{-2} h^{-1} and in imported salt has range between 0.0007 and 0.0011 Bq m^{-2} h^{-1} with average 0.0009 Bq m^{-2} h^{-1} but in rock salt has range between 0.0016 and 0.0021 Bq m^{-2} h^{-1} with average 0.0018 Bq m^{-2} h^{-1} as shown in **Table 1**, so the percentage of radon in rock salt higher than in other type of salt.

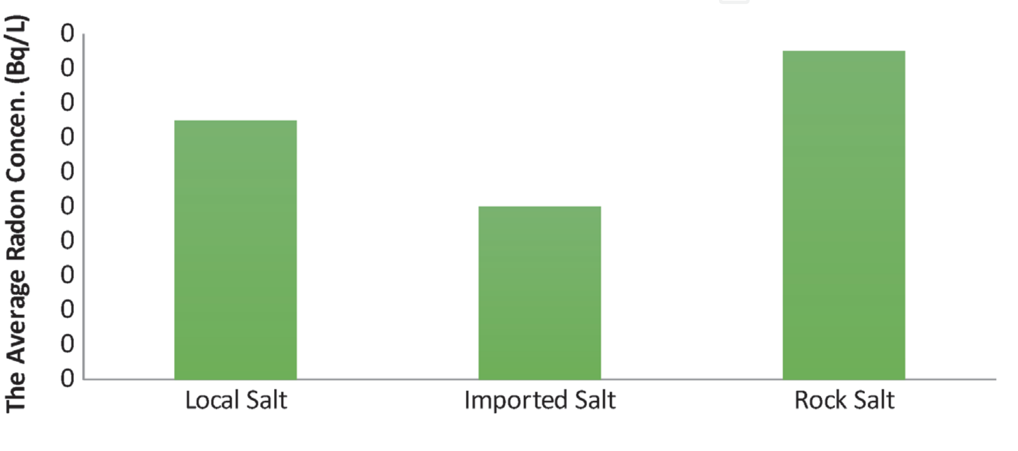

Figure 2.
Variation of radon concentration with different salt types.

Salt type	Sample code	Rn-222 (Bq/m^3)	Exhalation rate ($mBqm^{-2}h^{-1}$)	Effective dose (mSv/y)
Local	L1	335.36	0.0011	7.25
	L2	409.89	0.0014	8.86
	L3	558.94	0.0019	12.08
	L4	484.42	0.0016	10.47
Range	R	335.46–558.94	0.0011–0.0019	7.25–12.08
Average	Av	447.1525	0.0015	9.665
Imported	I1	223.58	0.0007	4.83
	I2	298.10	0.0010	6.44
	I3	260.84	0.0008	5.64
	I4	335.36	0.0011	7.25
Range	R	223.58–335.36	0.0007–0.0011	4.83–7.25
Average	Av	279.47	0.0009	6.04
Rock	R1	521.68	0.0017	11.27
	R2	484.42	0.0016	10.47
	R3	558.94	0.0018	12.08
	R4	633.47	0.0021	13.69
Range	R	484.42–633.47	0.0016–0.0021	10.47–13.69
Average	Av	549.6275	0.0018	11.8775

Table 1.
The radon concentration, annual effective dose and radon exhalation rate for edible salt by CR-39.

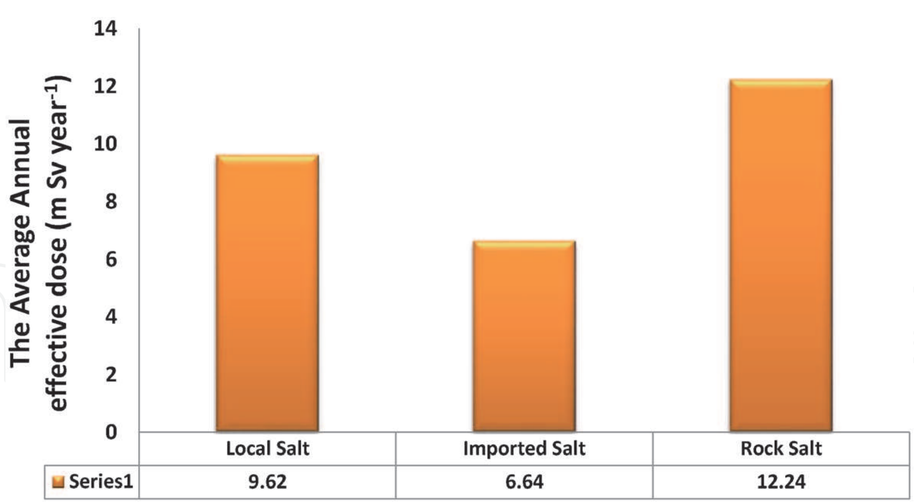

Figure 3.
The variation between the annual effective dose and type of salt.

Sodium is an important mineral needed to maintain your electrolyte balance. Excess sodium is secreted in urine, so determine the percentage of purity (concentration of NaCl) in the samples using titrimetric Mohr method it is found that 70% in local salt, 80% of imported salt and 55% in the rock salt, this difference may be attributed to the quality of purification processes. Hence, by combing chemical and physical analysis it can be concluded that the present study that used salt are not safe for rock salt so recommended to not used this type of salt in cooking food and used it in other purpose.

3.2 The radon in food

The data of track density (track/cm^2), concentration of radon-222 (Bq/m^3), effective radium content (Bq/kg), exhalation rate (mBqm^{-2} h^{-1}), and annual

Foods type	Sample code	Track density (track/cm^2)	Rn-222 (Bq/m^3)	Effective radium content (Bq/kg)	Exhalation rate (mBqm^{-2} h^{-1})	Effective dose (mSv/y)
Coffee	C1	28571.43	297.62 ± 10.92	6.94 ± 0.26	415.01 ± 15.22	7.51 ± 0.28
	C2	24489.80	255.10 ± 19.79	5.95 ± 0.47	355.73 ± 27.58	6.44 ± 0.50
	C3	22448.98	233.84 ± 24.22	5.46 ± 0.57	326.08 ± 33.76	5.90 ± 0.61
Average	Av	25170.07	262.19 ± 18.31	6.12 ± 0.43	365.61 ± 25.52	6.61 ± 0.46
Powder milk	P1	36734.69	382.65 ± 6.81	8.93 ± 0.15	533.59 ± 9.51	9.65 ± 0.17
	P2	30612.24	318.88 ± 6.49	7.44 ± 0.16	444.66 ± 9.04	8.04 ± 0.16
	P3	28571.43	297.62 ± 10.92	6.94 ± 0.26	415.01 ± 15.22	7.51 ± 0.28
Average	Av	31972.79	333.05 ± 8.07	7.77 ± 0.19	464.42 ± 11.25	8.40 ± 0.20
Tea	T1	28571.43	297.62 ± 10.92	6.94 ± 0.26	415.01 ± 15.22	7.51 ± 0.28
	T2	30612.24	318.88 ± 6.49	7.44 ± 0.16	444.66 ± 9.04	8.04 ± 0.16
	T3	20408.16	212.59 ± 28.65	4.96 ± 0.68	296.44 ± 39.94	5.36 ± 0.72
Average	Av	26530.61	276.36 ± 15.35	6.45 ± 0.37	385.37 ± 21.40	6.97 ± 0.39
Powder coconut	O1	16326.53	170.07 ± 37.52	3.97 ± 0.88	237.15 ± 52.31	4.29 ± 0.95
	O2	18367.35	191.33 ± 33.08	4.46 ± 0.78	266.79 ± 46.13	4.83 ± 0.83
	O3	14285.71	148.81 ± 41.95	3.47 ± 0.99	207.51 ± 58.49	3.75 ± 1.06
Average	Av	16326.53	170.07 ± 37.52	3.97 ± 0.88	237.15 ± 52.31	4.29 ± 0.95
Rice	R1	20408.16	212.59 ± 28.65	4.96 ± 0.68	296.44 ± 39.94	5.36 ± 0.72
	R2	34693.88	361.39 ± 2.37	8.43 ± 0.05	503.95 ± 3.33	9.12 ± 0.06
	R3	32653.06	340.14 ± 2.06	7.94 ± 0.05	474.30 ± 2.86	8.58 ± 0.05
Average	Av	29251.70	304.71 ± 11.03	7.11 ± 0.26	424.90 ± 15.38	7.69 ± 0.28
Cornstarch	S1	55102.04	573.98 ± 46.70	13.39 ± 1.08	800.38 ± 65.14	14.48 ± 1.18
	S2	44897.96	467.69 ± 24.54	10.91 ± 0.57	652.17 ± 34.23	11.80 ± 0.62
	S3	48979.59	510.20 ± 33.40	11.90 ± 0.77	711.45 ± 46.59	12.87 ± 0.84
Average	Av	49659.86	517.29 ± 34.88	12.07 ± 0.81	721.33 ± 48.65	13.05 ± 0.88
Flour	F1	26530.61	276.36 ± 15.36	6.45 ± 0.36	385.37 ± 21.40	6.97 ± 0.39
	F2	18367.35	191.33 ± 33.08	4.46 ± 0.78	266.79 ± 46.13	4.83 ± 0.83
	F3	22448.98	233.84 ± 24.22	5.46 ± 0.57	326.08 ± 33.76	5.90 ± 0.61
Average	Av	22448.98	233.84 ± 24.22	5.46 ± 0.57	326.08 ± 33.76	5.90 ± 0.61
Sugar	U1	61224.49	637.76 ± 60.00	14.88 ± 1.39	889.32 ± 83.68	16.09 ± 1.51
	U2	73469.39	765.31 ± 86.60	17.86 ± 2.01	1067.18 ± 120.77	19.31 ± 2.19
	U3	67346.94	701.53 ± 73.30	16.37 ± 1.70	978.25 ± 102.22	17.70 ± 1.85
Average	Av	67346.94	701.53 ± 73.30	16.37 ± 1.70	978.25 ± 102.22	17.70 ± 1.85

Table 2.
Track density (track/cm^2), Radon-222 concentration (Bq/m^3), effective radium content (Bq/kg), exhalation rate (mBqm^{-2} h^{-1}), and annual effective dose (mSv/y) for household foods.

effective dose (mSv/y) for eight types from household foods are presented in **Table 2**. The average activity concentrations of Rn-222 are 262.19 ± 18.31, 333.05 ± 8.07, 276.36 ± 15.35, 170.07 ± 37.52, 304.71 ± 11.03, 517.29 ± 34.88, 233.84 ± 24.22, and 701.53 ± 73.30 Bq/m^3 for coffee, powder milk, tea, powder coconut, rice, cornstarch, flour, and sugar respectively. Its observed from **Figure 4**. There are a large variations in the values of radon concentrations along all the samples, while the maximum values of Rn-222 concentration are observed at sugar, and cornstarch are 701.53 ± 73.30, and 517.29 ± 34.88 Bq/m^3 respectively, and the lowest value was observed at powder coconut is 170.07 ± 37.52 Bq/m^3. This variation may be due to the differences in the nature of these samples and also its bases content [2]. The gained values of radon concentrations for coffee, powder milk, tea, powder coconut, rice, and flour were found to be lower than the recommended value 400 Bq/m^3 [18], but its concentrations for cornstarch, and sugar were relatively higher than the recommended value. The high values of radon concentrations in foods are due to the presence of any type of ionizing radiation found in the air, soil or water which are transferred to the food and are grown on it [19]. The source of radon in foods is mainly from the activity concentration of its parent Ra-226. When radionuclide such as radium intake from the soil and irrigation water through the root and as a result of that it is transferred to foods [20]. When human are ingested radon daughters undergoes radioactive decay are transported to lung and causes changes to DNA structures. Also, several studies on lung cancer indicate the role of radon and thoron in causing the same [21].

Table 2 displays the average values of effective radium content are 6.12 ± 0.43, 7.77 ± 0.19, 6.45 ± 0.37, 3.97 ± 0.88, 7.11 ± 0.26, 12.07 ± 0.81, 5.46 ± 0.57, and 16.37 ± 1.70 Bqkg^{-1} for coffee, powder milk, tea, powder coconut, rice, cornstarch, flour, and sugar respectively. All values of effective radium content for all types of household foods were found to be lower than the permission level of 370 Bq kg^{-1} [22]. The average values of exhalation rate of radon are 365.61 ± 25.52, 464.42 ± 11.25, 385.37 ± 21.40, 237.15 ± 52.31, 424.90 ± 15.38, 721.33 ± 48.65, 326.08 ± 33.76, and 978.25 ± 102.22 mBqm^{-2} h^{-1} for coffee, powder milk, tea, powder coconut, rice, cornstarch, flour, and sugar respectively as shown at **Table 1**. A positive strong correlation was observed between effective radium content with both radon concentration, and exaltation rate with linear coefficients (R^2 = 1) as revealed at **Figure 5a** and **b**. The correlations coefficients are positively linear, these

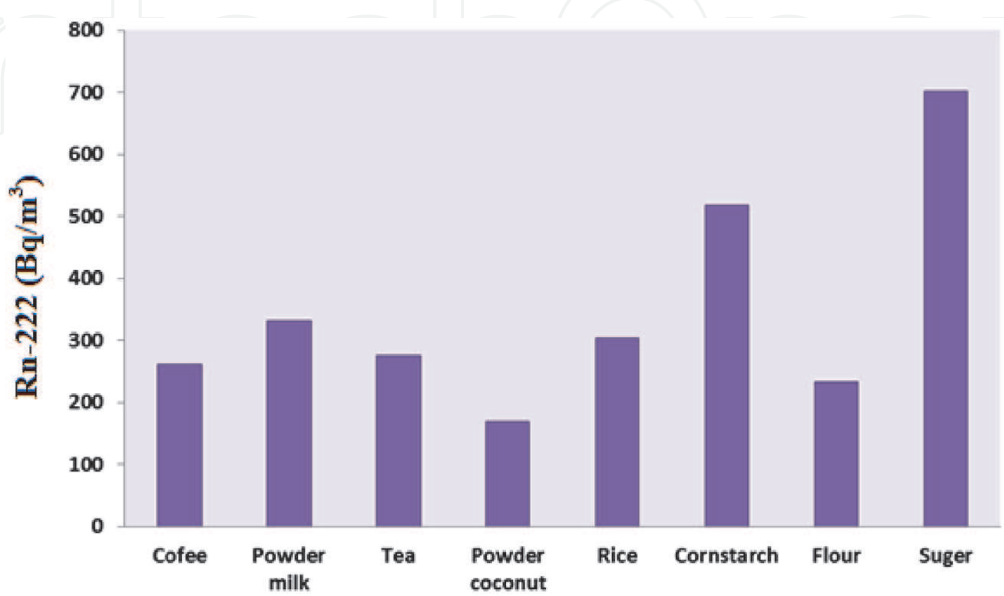

Figure 4.
Radon-222 concentrations for different types for household foods.

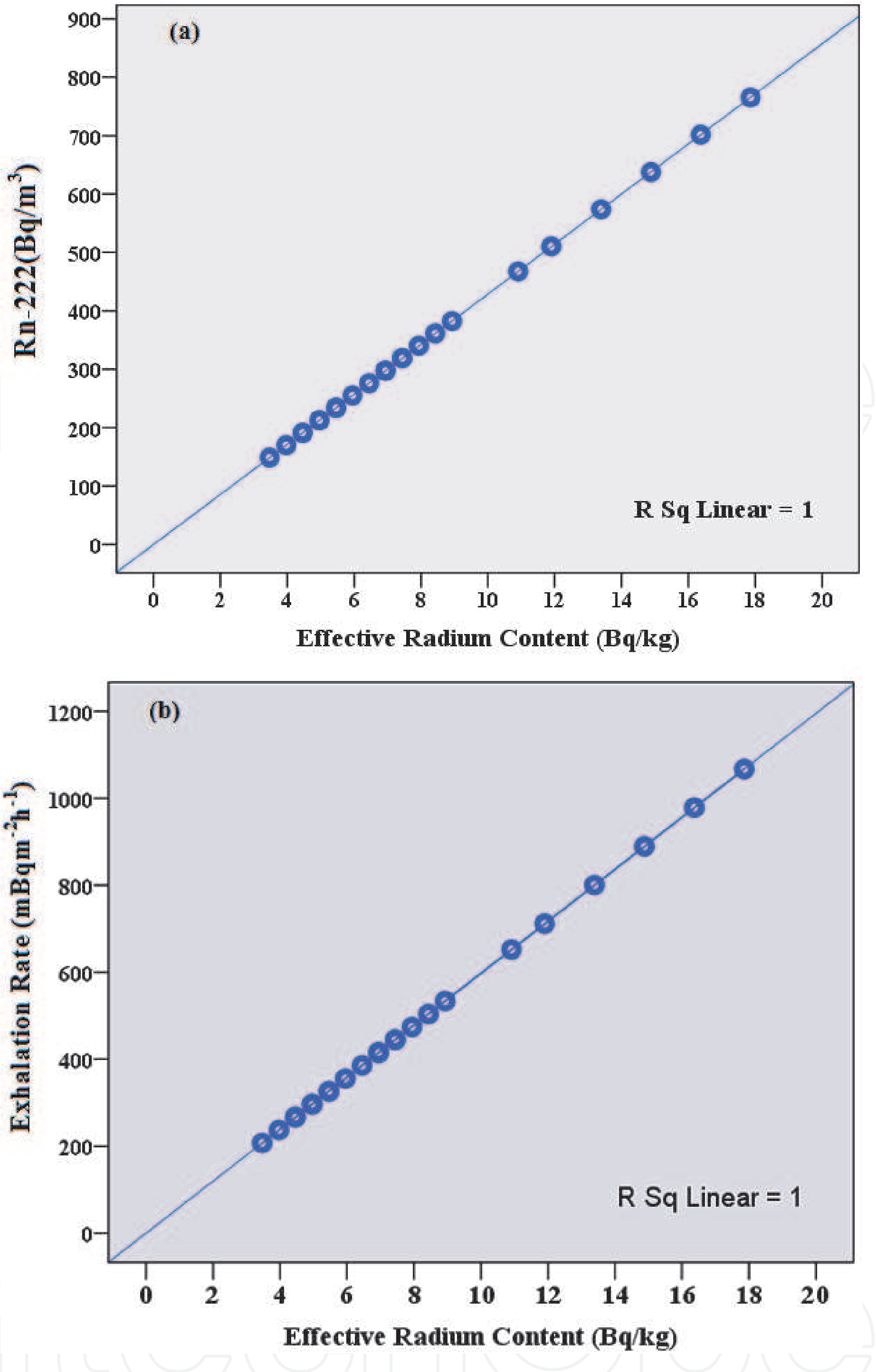

Figure 5.
Relations between effective radium content with (a) Rn-222 (Bq/m^3), (b) exhalation rate (mBqm^{-2} h^{-1}).

may be due to the values of radon concentrations and exhalation rate are mainly dependent on the values of effective radium, and the radon exhalation analysis is significant for knowing the relative impact of the material to the total radon concentration found in food samples and useful to study radon health hazard [23, 24].

We can see from **Figure 6** the high value of effective dose was observed in sugar, and the lower value of effective dose was observed at powder coconut, and there are a large variations in the values of effective dose for all the types of samples as 6.61 ± 0.46, 8.40 ± 0.20, 6.97 ± 0.39, 4.29 ± 0.95, 7.69 ± 0.28, 13.05 ± 0.88, 5.90 ± 0.61, and 17.70 ± 1.85 mSv/y for coffee, powder milk, tea, powder coconut, rice, cornstarch, flour, and sugar respectively. All values of effective dose within the recommended limit (3–10 mSv/y) [25], except its values for cornstarch and sugar are relatively high.

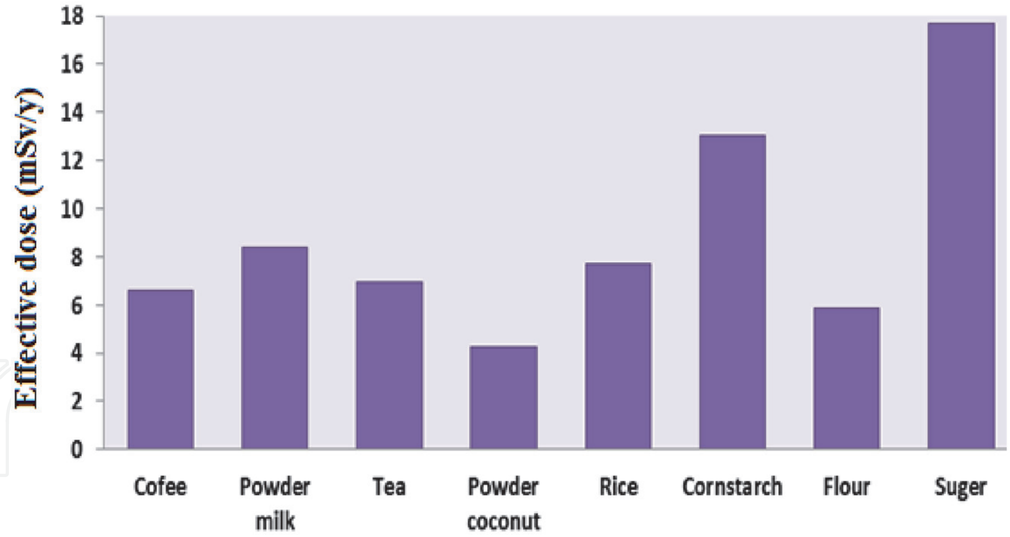

Figure 6.
Average values of annual effective dose for different types of household foods.

The values of transfer factor (TF) for radionuclides Rn-222, and Ra-226 in different types of household foods were presented at **Table 3**. The values of TF of Rn-222 varied from 0.60 ± 0.17 to 3.06 ± 0.35 with an average of 1.40 ± 0.11, while the values of TF of Ra-226 varied from 0.11 ± 0.029 to 0.54 ± 0.060 with an average of 0.25 ± 0.02. All values of TF for both radionuclides Rn-222, and Ra-226 are high, this may be due to organic substance content or small pH number of soil, so the radionuclides are absorbed at high levels through plants or seeds due to

Foods type	Sample code	TF for Rn-222	TF For Ra-226
Coffee	C1	1.19 ± 0.04	0.21 ± 0.008
	C2	1.02 ± 0.08	0.18 ± 0.015
	C3	0.94 ± 0.10	0.17 ± 0.017
Average	Av	1.05 ± 0.07	0.19 ± 0.013
Powder milk	P1	1.53 ± 0.03	0.27 ± 0.004
	P2	1.28 ± 0.03	0.23 ± 0.004
	P3	1.19 ± 0.04	0.21 ± 0.008
Average	Av	1.33 ± 0.03	0.24 ± 0.006
Tea	T1	1.19 ± 0.04	0.21 ± 0.008
	T2	1.28 ± 0.03	0.23 ± 0.004
	T3	0.85 ± 0.11	0.15 ± 0.021
Average	Av	1.11 ± 0.06	0.20 ± 0.011
Powder coconut	O1	0.68 ± 0.15	0.12 ± 0.027
	O2	0.77 ± 0.13	0.14 ± 0.023
	O3	0.60 ± 0.17	0.11 ± 0.029
Average	Av	0.68 ± 0.15	0.12 ± 0.026
Rice	R1	0.85 ± 0.11	0.15 ± 0.021
	R2	1.45 ± 0.01	0.26 ± 0.002
	R3	1.36 ± 0.01	0.24 ± 0.002
Average	Av	1.22 ± 0.04	0.22 ± 0.008

Foods type	Sample code	TF for Rn-222	TF For Ra-226
Cornstarch	S1	2.30 ± 0.19	0.41 ± 0.033
	S2	1.87 ± 0.10	0.33 ± 0.017
	S3	2.04 ± 0.13	0.36 ± 0.023
Average	Av	2.07 ± 0.14	0.37 ± 0.024
Flour	F1	1.11 ± 0.06	0.20 ± 0.010
	F2	0.77 ± 0.13	0.14 ± 0.023
	F3	0.94 ± 0.10	0.17 ± 0.017
Average	Av	0.94 ± 0.10	0.17 ± 0.017
Sugar	U1	2.55 ± 0.24	0.45 ± 0.042
	U2	3.06 ± 0.35	0.54 ± 0.060
	U3	2.81 ± 0.29	0.50 ± 0.052
Average	Av	2.81 ± 0.29	0.50 ± 0.051

Table 3.
Transfer factor of Radon-222, and Ra-226 for different types of household foods.

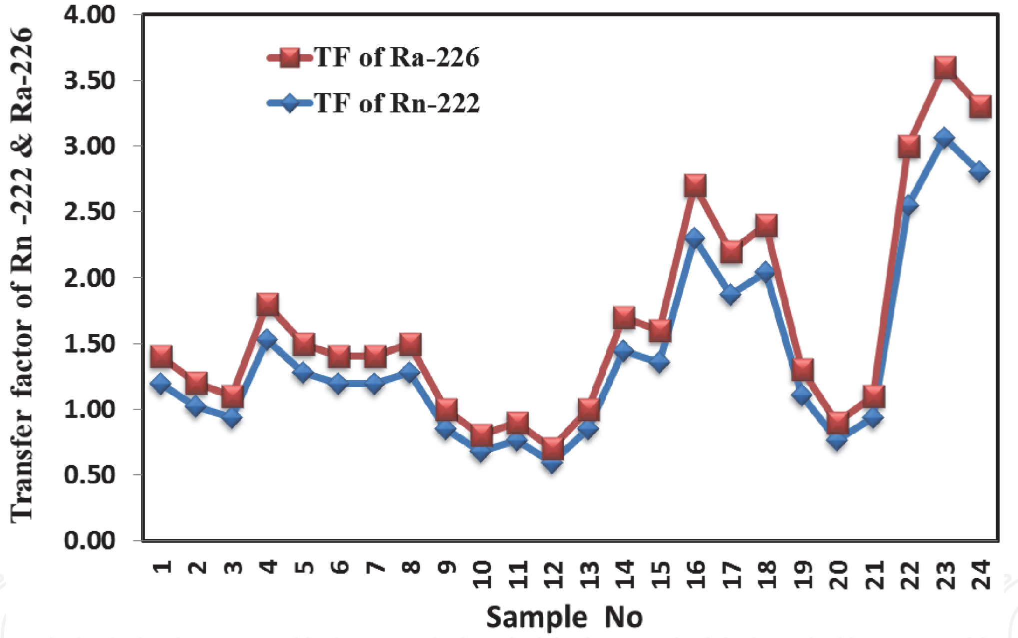

Figure 7.
Transfer factor of Ra-222, and Ra-226 for different types of household foods.

increase in the value of organic matter in the soil. Therefore, the uptake of radium in plant increases by increasing the concentration of organic acids and organic acids especially citric acid play an effective role on the uptake of Ra-226 by the plants due to pH reduction and complex formation of organic acids with elements in the soil. [15, 16, 26]. **Figure 7** shows there are a wide range of variations in the values of transfer factor of Rn-222, and Ra-226 along all the samples.

4. Conclusion

This chapter deals with the assessment of radioactive isotopes (Rn-22, and Ra-226) in various natural environmental samples. Some types of household foods (coffee, tea, powder milk, rice, flour, cornstarch, and powder coconut) and different types of salt have been analyzed for radon, and radium concentrations using closed-can technique based on Nuclear Track Detectors (SSNTD) CR-39. The range of radon −222 concentrations at different types of household foods are 170.07 (at powder coconut) −701.53 (at sugar) Bq/m^3, and the values of Radon-222 are higher than the recommend value of ICRP for cornstarch and sugar. All values of effective radium content for all food samples are lower than the recommended value. Exhalation rate of radon is relatively high at all samples. The average values of annual effective dose in mSv/y are within the recommended limit of ICRP values except its values for cornstarch and sugar are relatively high, and there are a wide range of variations in the values of transfer factor for Rn-222, and Ra-226 for all types. Then all types of foods which are analysis in this study are safe for using except the kinds of sugar and cornstarch.

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