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Estimation of annual effective dose to the adult Egyptian population due to natural radioactive elements in ingestion of spices

Rafat M. Amin[1] and Fawzia Ahmed[2]

[1]Physics Department, Faculty of science, Beni Suef University, Beni Suef, Egypt
[2]Radiation Measurement Department, National Institute for Standards, Egypt

ABSTRACT

Concentrations of naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K were estimated in spices for the adult population of Egyptian using gamma spectrometry. The average activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K were respectively 40.8, 18.7 and 578.8Bq kg^{-1}. The total annual external gamma effective dose in the stores due to spices ranged between 4.3μSvyr^{-1} and 26.8μSvyr^{-1} while the average of annual internal committed effective doses of 11.4, 4.3 and 3.6 μSv yr^{-1}, respectively. The net radiological impact of these radionuclides is 19.3μSv yr^{-1}. This value gives cancer risk factor of 4.8 × 10^{-5}and loss of life expectancy of 0.095 days only. Whereas ICRP cancer risk factor for general public is 2.5 × 10^{-3} and total risk involve from the all natural radiation sources based on global average annual radiation dose of 2.4 mSv yr^{-1} is 6.0 × 10^{-3}. The estimated cancer risk shows that probability of increase of cancer risk from Egyptian spices is only a minor fraction of ICRP values. Therefore, the spices do not pose any significant health hazard and is considered radiologically safe for human consumption.

Keywords: radioactivity, gamma ray spectroscopy, annual absorbed dose, cancer risk, spices.

INTRODUCTION

Food is known to contain natural and artificial radionuclides that, after ingestion, contribute to an effective internal dose. It has been estimated that a large portion, at least one eighth, of the mean annual dose due to natural sources is caused by the intake of food [1]. Average radiation doses to various organs of the body also represents important pathway for long term health considerations.

^{232}Th,^{238}U(^{226}Ra) and ^{40}K are three long-lived naturally occurring radionuclides present in the earth crust. They generally enter human body through the food chain and also through the inhalation of the suspended dust in the air. When inhaled or ingested these elements accumulate in critical organs and deliver radiation doses. Thorium accumulates in human lungs, liver and skeleton tissues, uranium in lungs and kidney and potassium in muscles. Depositions of large quantities of these radionuclides in particular organs produce radiation damages, biochemical and morphological changes. This results in weakening of immune systems, development of various types of diseases/cancers and increase in mortality rate. The potential harmfulness is based on their long half lives and chemical behavior (^{232}Th: 1.4 × 10^{10} yr, ^{238}U: 4.47 × 10^{9} yr and ^{40}K: 1.28 ×10^{9} yr). ^{232}Th is mainly radiotoxic, ^{238}U is both radiotoxic as well as chemically toxic whereas ^{40}K is radiotoxic as well as nutritionally important element [2]. Owing to the health risks associated with the exposure to indoor radiation, many governmental and international bodies such as the international commission on Radiological Protection (ICRP), the World Health Organization (WHO), etc. have adopted strong measures aimed at minimizing such exposures [3].

Spices and herbs are valued for their distinctive flavors, colors and aromas and are among the most versatile and widely used ingredient in food preparation and processing throughout the world. The main objective of this study is therefore to determine the activity concentration levels of ^{226}Ra, ^{232}Th, and ^{40}K in some spices, consumed by the population of Egypt, to ensure that food safety is not compromised and that the external and internal effective doses are within the specified safety limits.

MATERIALS AND METHODS

Sample preparation

The samples examined in this study were representative of almost all the local and imported products that were sold on the Egyptian market at the time of the study. The samples were bought from retailers, and two samples were collected from each kind for good estimation of the results. All samples examined were powdered to average particle size lower than 1 mm. Samples were oven dried at 100 ^oC, homogenized, accurately weighed, and then packed in appropriate measuring geometries and sealed, in order to prevent ^{222}Rn leakage. Measurements were carried out on the samples after an ageing time of about 30 days, in order to allow the re-establishment of radioactive equilibrium between ^{222}Rn and its shortlived daughter products.

Gamma spectrometry

In the present work, the measurements of natural radioactivity levels were performed by gamma-ray spectrometry, using a high-purity germanium (HpGe) detector connected to a multichannel analyzer. Detailed information concerning the HPGe-detector calibration and also the procedures followed can be found elsewhere [4].

The activities of the uranium and thorium decay series were determined by measuring the areas of the peaks of some members located downstream of the radon nuclides (^{222}Rn for ^{238}U chain and ^{220}Rn for ^{232}Th chain). The secular equilibrium between radon nuclides and their daughter products is assured by the ageing time of 30 days after sealing.

The gamma-energy lines of 351.9(37.1%) keV from ^{214}Pb and 609.3 (46.1%)keV, 1120.3 (15%)keV and 1764.5(16%)keV from^{214}Bi were used to represent the ^{238}U (^{226}Ra) series, while 338.4(12%)keV and 911.2 (29%) keVfrom ^{228}Ac and 583.0 (86%) keV from ^{208}Tlwere used to represent the ^{232}Th series and 1460.8(10.7%)keV for^{40}K gamma-line.Prior to sample measurement, the environmental gamma background at the laboratory site was determined with an empty Marinelli beaker under identical measurement conditions. It was later subtracted from the measured γ-ray spectra of each sample. Counting time was 60 000 s.

Determination of radiological impact parameters in spices

The activity concentrations for the natural radionuclides in the measured samples were evaluated using the following equation:

$$A=(C_S-C_B)/\varepsilon_\gamma.I_\gamma.M \quad (1)$$

whereC_S is cps for sample, C_B is cps for background, $\varepsilon_\gamma$is the detector efficiency of the specific γ-ray, I_γ is the absolute transition probability of that γ-decay, and M is the mass of the sample in kg.

To estimate annual external effective dose, account must be taken of (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor. Annual estimated average effective dose equivalent received by a member is calculated using a conversion factor of 0.7 $Sv.Gy^{-1}$, which is used to convert the absorbed rate to human effective dose equivalent with occupancy of 50% for indoors.

The annual external effective doses are determined as follows[5]:

$$E\ (nSv)= \text{Absorbed Dose rate}(nGyh^{-1})\times 8760h\times 0.5 \times 0.7\ SvGy^{-1} \quad (2)$$

where absorbed dose rate($nGyh^{-1}$) = $0.462 \times A_{Ra} + 0.604 \times A_{Th} + 0.0417 \times A_K$

where A_{Ra}, A_{Th} and A_K are the specific activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K, respectively

Effective dose due to ingestion

Effective dose is a useful concept that enables the radiation doses from different radionuclides and from different types and sources of radioactivity to be added. Estimates of the radiation induced health effects associated with intake of radionuclides in the body are proportional to the total dose delivered by the radionuclides while resident in the various organs. Radiation doses ingested are obtained by measuring radionuclide activity in foodstuffs (Bq kg^{-1}) and multiplying these by the masses of food consumed over a period of time (kg d^{-1} or kg y^{-1}). A dose conversion factor (Sv Bq^{-1}) can then be applied to give an estimate of ingestion dose. Thus, the ingested dose is given by[6, 7]:

Dose(Sv/y)= Concentration (Bq/kg)×Annual intake(kg/y)× DCF (Sv/Bq) (3)

Where DCF is the standard dose conversion factor, which is equal to 0.28μSv/Bq for ^{226}Ra, 0.23μSv/Bq for ^{232}Th and 0.0062 μSv/Bq for ^{40}K.

RESULTS AND DISCUSSION

Natural radioactivity in the spices

Table 1 summarizes the results of measurements of natural radionuclide (^{226}Ra, ^{232}Th and ^{40}K) concentrations in the collected spices samples. The activity concentrations are given in Bq/kg and the uncertainty in all measured values of natural radioactivity is within 3%.

The range of activity concentrations of ^{226}Raand^{232}Th in the selected samples in this study varies from 10.4Bq kg^{-1} (black pepper) to 77.9Bq kg^{-1} (thyme) and 5.9Bq kg^{-1} (parsley) to 57.4Bq kg^{-1} (cumin), respectively.

The range of ^{40}K concentration was found to vary between 130 Bq kg^{-1} (black pepper) to 1416 Bq kg^{-1} (marjoram). The concentration of ^{40}K was the highest, possibly due to the concentrations of ^{40}K in the soil due to the heavy use of fertilizers by farmers. The transfer factor of ^{40}K is higher than some natural radioisotopes [8]. However, ^{40}K is a key element in regulating many functions and it is homeostatically controlled in living organisms. For that reason, its potassium content is held constant by metabolic processes.

Substantial change in the values of ^{226}Ra, ^{232}Th and ^{40}K in spices samples may be due to the variety in the levels of natural radioactivity in soil from across the world .The studied spices are imported from different countries. The transfer factor can be a second reason for this variety, because it is affected by the meta-selective function of the plant during the uptake of elements so as to maintain the mechanism of homeostasis in a normal environment.

Over the world, the concentrations of radionuclides in grain products, leafy vegetables and root vegetables are less than 1Bq/kg [5], except for some countries which have excess Bq/kg in their food products. This indicates the high content of natural radionuclides in all studied spices, but the crucial factor that must taken into consideration is the annual food consumption of grain products, leafy vegetables, and root vegetables, which is approximately 370 kg for an adult, compared with about 1 kgofspices.

Annual effective doses

Dose from the Spices Store

The annual external effective doses due to exposure for each radionuclide (^{226}Ra, ^{232}Th and ^{40}K) to these spices in stores are shown in fig. 1. The results show that the concentration of ^{226}Ra, ^{232}Th and ^{40}K in the spices ranged from 14.7μSv (black pepper) to 110.4μSv (thyme), 11.9 μSv (black pepper) to 106.3 μSv (cumin) and 16.7 μSv (black pepper) to 181 μSv (majoram), respectively. The calculation is based on using an occupancy factor equal to 0.5 (4380 h/year), which is suitable for store workers who spend about half the day in their work. These values are compared with the average worldwide exposure to natural radiation sources. The results show that the total annual external effective dose ranged from 4.3μSv (black pepper) to 26.8μSv (marjoram), which constitute 1% to 6%, respectively, of the total indoor exposure to natural radiation sources, which is given as 410μSv with a 0.8 occupancy factor[5].

Effective dose due to ingestion

The ingestion dose due to each radionuclide are presented in table 2 and compared with the global dose due to ingestion of naturally occurring ^{226}Ra, ^{232}Th, ^{40}K radionuclides excluding radon and thoron reported by UNSCEAR (2000). The annual effective ingestion doses due to intake of^{226}Ra varied from 2.9μSv y^{-1}in black pepper to 21.8μSv y^{-1} in thyme. Most samples show highly significant increases in their ingestion doses over the values reported by UNSCEAR (2000), with percentage increases ranging from 114% (cardamom) to 346% (thyme).

The dose received from ^{232}Th due to consumption of spices varied from 1.4 μSv y^{-1} in parsley to 13.2 μSv y^{-1} in cumin which constitute 368% (parsley) to 3473% (cumin) of the total ingestion dose (0.38 μSv) as reported by (UNSCEAR, 2000).

The report from UNSCEAR (*2*000) shows that the total ingestion dose from the ^{238}U and ^{232}Th series is higher than the sub-total given in table 2 for the results reported here for ^{226}Ra and ^{232}Th. This difference comes from ^{210}Po, ^{210}Pb and ^{228}Ra, which are not considered in our measurements.

The dose from ingestion of ^{40}K for all samples can be considered to be low when comparable with UNSCEAR dose level(170 μSv y^{-1})for all foods.

The low values of the total annual effective ingestion doses due to intake of spices is due to the scale of the annual intake (1 kg/year) when compared with a few hundred kilograms per year for the total food intake.

Cancer risk

The risk incurred by a population is estimated by assuming a linear dose-effect relationship with no threshold as per ICRP practice. For low doses ICRP fatal cancer risk factor is 0.05 Sv^{-1}[9]. The risk factor states the probability of a person dying of cancer increases by 5% for a total dose of 1 Sv received during his lifetime. Therefore, the probability of death from cancer due to 'natural incidence' increases from about 25% to 30% following a total lifetime exposure of 1 Sievert.

The average annual committed effective dose for the measured spices in this study, 19.3 μSv, is used to estimate cancer risk for an adult person using the following relationship:

$$\text{Risk} = \text{Dose(Sv)} \times \text{risk factor } (Sv^{-1}) \quad (4)$$

The estimated cumulative annual dose of 19.3 μSv to adults is used and life-time (50 yr) exposure is estimated as 0.965 mSv, which gives a risk factor of 4.8×10^{-5} due to spices. It shows that probability of increase of cancer risk from daily diet is 0.0048% only. This value is a negligible fraction of the total risk involve (6.0×10^{-3}) from all natural radiation sources based on global average annual radiation dose of 2.4 mSv yr^{-1} to man[5].

The estimated values are significantly less than the ICRP cancer risk of 2.5×10^{-3} based on annual dose limit of 1 mSv for general public, which gives annual death probability of 10^{-5}, i.e. 1 in 100,000 [10]. The risk of cancer from measured radiation is also compared with other kinds of health risks using Cohen and Lee estimates [11]. The authors estimated an average loss of 15 days from occupational exposure of 3 mSv yr^{-1} from age 18 to 65. Based on their estimates the calculated health risk from the measured average radiation dose 0.019mSv yr^{-1} from present study is only 0.095 days. It is therefore concluded that 0.019mSv yr^{-1} annual radiation dose attributable to spices intake of the three naturally occurring radionuclides (radium, thorium and potassium) in Egyptian would not pose any significant

Table 1 Activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in the spices

Sample code	^{226}Ra(Bq/kg^{-1})	^{232}Th(Bq/kg^{-1})	^{40}K(Bq/kg^{-1})
Parsley	42.9 ±1.5	5.9± 0.2	932 ±29
Marjoram	44.9 ±1.4	12.4 ±0.4	1416±44
Black cumin	33.8±1.1	40.3±1.4	208±6.3
Turmeric	13.6±0.5	7.9±0.3	1161±36
Rosemary	34.2±1.2	15.2±0.5	881±27
Thyme	77.9±2.9	14.5±0.5	851±20
Red pepper	70.8±2.1	13.9±0.4	162±5
Cumin	49.9±1.1	57.4±0.3	278±6
Coriander	45.8±1.7	17.9±0.6	911±28
Cardamom	25.6±0.9	20.5±0.7	459±14
Black pepper	10.4±0.3	6.5±0.2	130±4
Mastic	49.2±1.4	13.4±0.5	609±19
Bay leafs	21.2±0.8	32.4±1.1	235±7
Nutmeg	31.6±0.9	10.8±0.3	203±6
Galangal	59.7±2.1	11.9±0.4	246±7

Table2. Annual committed effective dose (μSv) of adult population of Egyptian from intake of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in the spices

Radionuclide	Annual committed effective ingestion dose (μSv)															
	parsley	marjoram	black cumin	turmeric	rosemary	thyme	red pepper	cumin	coriander	cardamom	black pepper	mastic	bay leaf	nutmeg	galangal	UNSCEAR, 2000
^{226}Ra	12	12.6	9.5	3.8	9.6	21.8	19.8	14	12.8	7.2	2.9	13.8	5.9	8.9	16.7	6.3
^{232}Th	1.4	2.9	9.3	1.8	3.5	3.3	3.2	13.2	4.1	4.7	1.5	3.1	7.5	2.5	2.7	0.38
Sub-total	13.4	15.5	18.8	5.6	13.1	25.1	23	27.2	16.9	11.9	4.4	16.9	13.4	11.4	19.4	120
^{40}K	5.8	8.8	1.3	7.2	5.5	5.3	1	1.7	5.6	2.8	0.81	3.8	1.5	1.3	1.5	170
Total	19.2	24.3	20.1	12.8	18.6	30.4	24	28.9	22.5	14.7	5.21	20.7	14.9	12.7	20.9	290

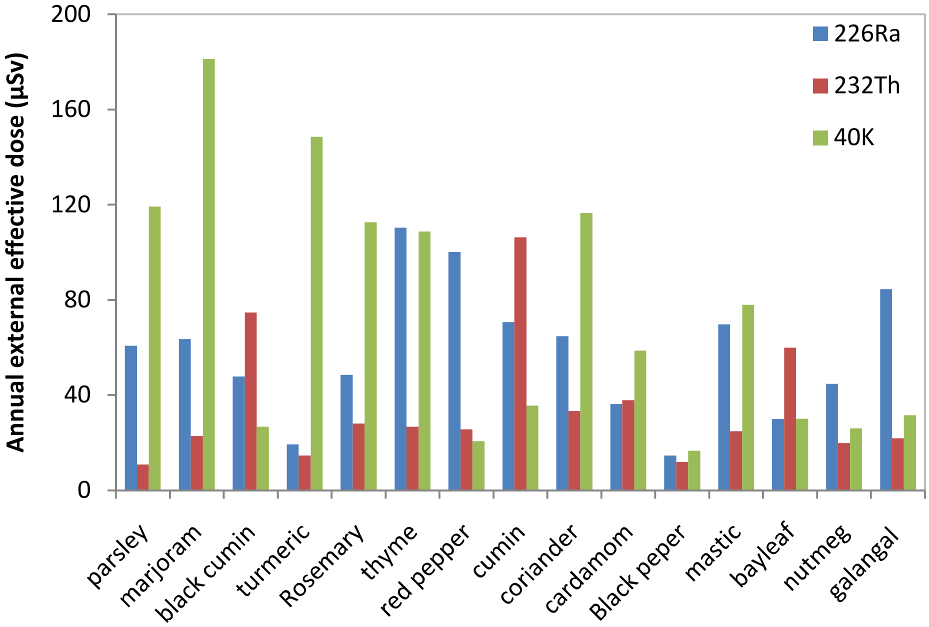

Fig. 1 The annual external effective dose due to exposure to the spices in stores

CONCLUSION

The study estimated the activity concentration of radionuclides ^{226}Ra, ^{232}Th and^{40}K by means of gamma ray spectrometry in different spices that are regularly consumed by the population of Egypt. The spice with the highest amount of ^{226}Ra was thyme. While the spice with the highest amount of ^{232}Th radionuclide was cumin. ^{40}K in spices is low when comparing with UNSCEAR dose level. The annual committed effective doses from the spices have been determined and cancer risk is estimated. The estimated committed effective doses are 11.4, 4.3 and 3.6 µSv yr^{-1}, for ^{226}Ra, ^{232}Th and ^{40}K respectively at annual intake of spices is proposed to be 1 kg/year. The net radiological impact of these radionuclides is 19.3 µSv yr^{-1}, which gives a cancer risk factor of 4.8 × 10^{-5}. The estimated risk has no significant health hazard and Egyptian spices areradiologically safe, as per international standards.

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