Radioprotection 2008
Vol. 43, n° 2, pages 225 à 237

DOI: 10.1051/radiopro:2008001

Article

^{238}U and ^{232}Th concentrations in various foodstuffs in Morocco and resulting radiation doses to the members of the public

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(Manuscript received 27 May 2007, accepted 3rd January 2008)

ABSTRACT **Uranium (^{238}U) and thorium (^{232}Th) concentrations were measured in different foods widely consumed in Morocco by using CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs). Data obtained were compared to those obtained by using isotope dilution mass spectrometry (IDMS). Total daily intakes of ^{238}U and ^{232}Th for a typical food basket were estimated to be 1.3 ± 0.1 mBq d^{-1} and 0.98 ± 0.08 mBq d^{-1}, 1.4 ± 0.1 mBq d^{-1} and 1.06 ± 0.08 mBq d^{-1}, 1.7 ± 0.1 mBq d^{-1} and 1.26 ± 0.08 mBq d^{-1} and 2.0 ± 0.1 mBq d^{-1} and 1.5 ± 0.1 Bq d^{-1} for the 2–7 years, 7–12 years, 12–17 years and adult's age groups, respectively. Alpha-activities due to annual ^{238}U and ^{232}Th intakes from the ingestion of the studied foodstuffs were determined in different organs and tissues of the human body of members of the public by using the ICRP gastrointestinal tract and systemic part models for these radionuclides. Committed equivalent doses due to annual intakes of ^{238}U and ^{232}Th were evaluated in the human body organs and tissues for different age groups of the Moroccan population by exploiting data obtained for alpha-doses deposited by 1 Bq of ^{238}U and 1 Bq of ^{232}Th in the considered human organs and tissues. The influence of the mass of the target tissue and activities due to ^{238}U and ^{232}Th on the committed equivalent doses due to annual intakes of these radionuclides in the organs and tissues of the human body was studied.**

Keywords: Nuclear-track detector / ingestion / ^{238}U and ^{232}Th intakes / equivalent dose / uranium / thorium / environment / natural radioactivity

Résumé **Concentrations en ^{238}U et ^{232}Th dans différents aliments au Maroc et doses de radiations en résultant pour les membres du public.**

Les concentrations en uranium (^{238}U) et en thorium (^{232}Th) ont été mesurées dans différents aliments largement consommés au Maroc, par l'utilisation d'une technique nucléaire basée sur la détermination des efficacités de détection des détecteurs CR-39 et LR-115 type II pour les particules alpha émises par l'^{238}U et le ^{232}Th et leurs descendants à l'intérieur des matériaux considérés. Les doses équivalentes engagées dues à l'^{238}U et au ^{232}Th dans des organes et tissus des individus marocains de différentes tranches d'âge suite à l'ingestion des aliments étudiés ont été calculées à l'aide des coefficients de dose équivalente par unité d'activité ingérée de la publication CIPR 69. L'influence du coefficient de dose équivalente et de l'incorporation de l'^{238}U et du ^{232}Th sur l'équivalent de dose engagée a été mise en évidence.

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1. Introduction

Naturally occurring radionuclides enter the human body mainly by inhalation of radon and thoron gases and their decay products (Misdaq *et al.*, 2001) and by ingestion of primordial radionuclides and their progeny: ^{40}K, and the ^{238}U and ^{232}Th series (Fisenne *et al.*, 1987; Shiraishi *et al.*, 2000, 1995; Dang *et al.*, 1990; Pietrzak-Fils *et al.*, 1997; Singh *et al.*, 1990). Due to their presence in soil and phosphate fertilizers, primordial radionuclides and their progeny are transferred *via* the food chain to human body. It is necessary to measure the radionuclide content of food and water samples to assess potential radiation doses and, if necessary, to take action to avoid the exposure of consumers to radiation. Three food categories, fish and shellfish, cereals (excluding rice) and vegetables are found to be the main contributors to the daily intakes of ^{238}U and ^{232}Th in the USA (Fisenne *et al.*, 1987). In Japan, two food categories, fish and shellfish, and vegetables are the main contributors to ^{238}U and ^{232}Th dietary intakes (Shiraishi *et al.*, 2000, 1995; Kuwahara *et al.*, 1997). Uranium and thorium concentrations have been measured in various food and drink samples in Hong-Kong by using gamma-ray spectrometry (Yu and Mao, 1999). Simultaneous determination of ^{238}U and ^{232}Th in some Indian biological reference materials has been performed by using neutron activation analysis and radiochemical separation (Dang *et al.*, 1992). However, this technique is both destructive and expensive. ^{238}U and ^{232}Th have been analysed in different food samples using inductively coupled plasma mass spectrometry (ICP-MS) which is also destructive (Shiraishi *et al.*, 2000). Committed effective doses to members of the Moroccan public due to ^{238}U and ^{232}Th in different foods were evaluated by using the ICRP ingestion dose coefficients (Misdaq and Bourzik, 2004).

In the work described here, CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) were used to evaluate uranium and thorium contents in various food material samples. Annual committed equivalent doses were determined for different organs of the human body of members of the Moroccan population from the intakes of ^{238}U and ^{232}Th by ingestion of various food materials.

2. Method of study

2.1. Determination of uranium and thorium concentrations in different food material samples

Various dry cereals, fresh fruits and vegetables, widely consumed in Morocco, were washed to remove adhering soil and analysed. Honey, milk and olive oil

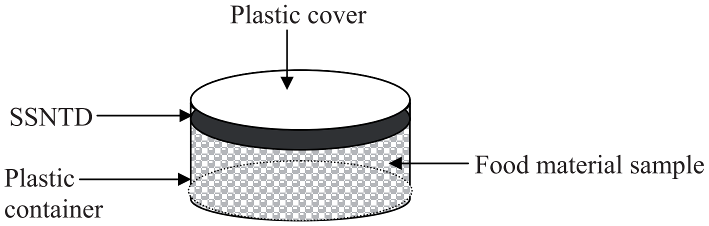

Figure 1 – Arrangement of the solid state nuclear track detectors (SSNTD) on a food material sample in a well-closed plastic container of radius q = 2 cm and depth D = 1 cm.

Schéma de la disposition des détecteurs solides de traces nucléaires sur un échantillon d'aliment à l'intérieur d'une capsule en plastique bien fermée de rayon q = 2 cm et de hauteur D = 1 cm.

material samples were also analysed. Disk-shaped Pershore Mouldings CR-39 (500 µm thickness) and Kodak LR-115 type II (12 µm cellulose nitrate on 100 µm polyester base) SSNTD films of 4 cm diameter were placed in close contact with a homogeneous food material sample separately in a hermetically sealed cylindrical plastic container of radius q (= 2 cm) for one month (Fig. 1). The cylinders containing dry materials were kept in a room at ambient temperature and pressure while the cylinders containing fresh materials (fruits, honey, milk and vegetables) were kept in a refrigerator at 10 °C for one month. During the exposure period, α-particles emitted by the ^{238}U and ^{232}Th series bombarded the SSNTD films. After the exposure of one month, the films were etched in two NaOH solutions at optimal conditions of etching, ensuring good sensitivities of the SSNTD and a good reproducibility of the registered track density rates: the first solution of 2.5 mol l^{-1} normality at 60 °C for 120 minutes for LR-115 type II films and the second solution of 6.25 mol l^{-1} normality at 70 °C for 7 hours for the CR-39 detectors (Misdaq *et al.*, 2000). After this chemical treatment, the track densities registered on the CR-39 and LR-115 type II detectors were measured by using an optical microscope. Backgrounds on the CR-39 and LR-115 II SSNTDs were evaluated by placing these films in empty well-closed plastic containers identical to those used for analysing food samples for one month and counting the resulting track densities. This operation was repeated ten times: track densities registered on the CR-39 and LR-115 II detectors were found to be identical within the statistical uncertainties on track counting. As the system is well-sealed (there is no escape of radon and thoron) and the exposure time was 30 days, one can assume radioactive secular equilibrium between uranium, thorium and their corresponding decay products. For our experimental etching conditions, the residual thickness of the LR-115 type II detectors measured by means of a mechanical comparator is 5 µm. This thickness defines the lower (E_{min} = 1.6 MeV) and upper (E_{max} = 4.7 MeV) energy limits for registration of tracks of α-particles in LR-115 type II films (Hafez and Naim, 1992). All α-particles emitted by the uranium and thorium series that reach the LR-115 detector at an angle lower than its critical angle of etching θ_c' with a residual energy between 1.6 MeV and 4.7 MeV are registered as bright track-holes. The CR-39 detector is sensitive to all α-particles reaching its surface at an angle smaller than its critical angle of etching θ_c. θ_c' and θ_c were calculated by using a method described in detail by Misdaq *et al.* (1999).

The homogeneity of food samples and reproducibility of method were checked by analysing ten samples of the same material. Track density production rates registered on the CR-39 and LR-115 type II track detectors and uranium and thorium contents of the ten samples were found to be similar within the statistical uncertainties on track counting.

By calculating the detection efficiencies of the CR-39 (ε_j^{CR} and $\varepsilon_j'^{CR}$) and LR-115 II (ε_j^{LR} and $\varepsilon_j'^{LR}$) SSNTDs for α-particles emitted by the uranium and thorium series inside a food material sample by using the "SSNTDDEαM" FORTRAN program (Misdaq *et al.*, 2000), and then by measuring track density rates (tracks cm^{-2} s^{-1}) registered on the CR-39 (ρ_G^{CR}) and LR-115 type II (ρ_G^{LR}), the ^{238}U C(U) and ^{232}Th C(Th) contents inside the considered material sample were determined by the relation (Misdaq *et al.*, 2000):

$$\frac{C(Th)}{C(U)} = \frac{A_U}{A_{Th}} \frac{\frac{S_d'}{S_d} \sum_{j=1}^{8} k_j \varepsilon_j^{CR} R_j - \frac{\rho_G^{CR}}{\rho_G^{LR}} \sum_{j=1}^{8} k_j \varepsilon_j^{LR} R_j}{\frac{\rho_G^{CR}}{\rho_G^{LR}} \sum_{j=1}^{7} k_j' \varepsilon_j'^{CR} R_j' - \frac{S_d'}{S_d} \sum_{j=1}^{7} k_j' \varepsilon_j'^{LR} R_j'} \tag{1}$$

and

$$C(U) = \frac{2 S_d' \rho_G^{LR}}{\pi q^2 d_s \left[A_U \sum_{j=1}^{8} k_j \varepsilon_j^{LR} R_j + \frac{C(Th)}{C(U)} A_{Th} \sum_{j=1}^{7} k_j' \varepsilon_j'^{LR} R_j' \right]} \tag{2}$$

where: S_d and S_d' are the surface areas of the CR-39 and LR-115 type II films, respectively. R_j and R_j' are the ranges in sample materials, of α-particles with an initial energy E_j emitted by the nuclei of the uranium and thorium series, respectively. k_j and k_j' are the branching ratios corresponding to the disintegration of the nuclei of the uranium and thorium series, respectively. A_U(Bq g^{-1}) = 0.0123 and A_{Th}(Bq g^{-1}) = 0.0041 are the specific activities of a sample for a ^{238}U content of 1 ppm (10^{-6} g g^{-1}), and a ^{232}Th content of 1 ppm (10^{-6} g g^{-1}), respectively. d_s is the density of the material sample (g cm^{-3}).

The relevant ranges of the emitted alpha-particles in food material samples and SSNTDs were calculated by using a TRIM (Transport of ions in materials) programme (Biersack and Ziegler, 1998). The TRIM code is a FORTRAN computer programme based on the theory of penetration of ions in solids as described in detail by Ziegler *et al.* (1985).

2.2. Evaluation of committed equivalent doses due to ^{238}U and ^{232}Th in the human body from the ingestion of different foodstuffs

The committed equivalent doses due to ^{238}U and ^{232}Th in the tissue T from the ingestion of a typical food basket, during one year, are respectively given by:

$$H_T(^{238}U) = I(^{238}U)h_T(^{238}U) \tag{3}$$

and

$$H_T(^{232}Th) = I(^{232}Th)h_T(^{232}Th) \tag{4}$$

where $I(^{238}U)$ (Bq y^{-1}) and $I(^{232}Th)$ (Bq y^{-1}) are respectively the ^{238}U and ^{232}Th intakes from the ingestion of a typical food basket. $h_T(^{238}U)$ (Sv Bq^{-1}) and $h_T(^{232}Th)$ (Sv Bq^{-1}) are the ingestion dose coefficients for the ^{238}U and ^{232}Th radionuclides, respectively (ICRP, 1995).

3. Results and discussion

3.1. ^{238}U and ^{232}Th intakes from the ingestion of different foodstuffs

The observed values of ^{238}U (C(U)) and ^{232}Th C(Th) contents in fruits, vegetables, cereals, honey, olive oil and milk material samples are shown in Table I. From the statistical uncertainty on track counting one can determine the uncertainty on track density production per unit time and then evaluate the uncertainty of the uranium and thorium contents determination which is about 8%. All the food samples (cereals, fruits, milk, honey, olive oil and vegetables) studied contain more thorium than uranium.

The same food material samples were analysed by using isotope dilution mass spectrometry (IDMS). Data obtained are in good agreement with those obtained by using our method (Tab. I).

TABLE I

Data obtained for the uranium (C(U)) and thorium (C(Th)) contents in different food materials from a typical food basket.
Résultats obtenus pour les concentrations en uranium (C(U)) et en thorium (C(Th)) dans différents aliments d'une corbeille alimentaire typique.

Food material sample	This method				Isotope dilution mass spectrometry	
	$A_c(^{238}U)$ (mBq kg^{-1})	$A_c(^{232}Th)$ (mBq kg^{-1})	$C(^{238}U)$ (ppm)	$C(^{232}Th)$ (ppm)	$C(^{238}U)$ (ppm)	$C(^{232}Th)$ (ppm)
banana	3.4 ± 0.2	2.2 ± 0.2	0.28 ± 0.02	0.54 ± 0.04	0.25 ± 0.01	0.51 ± 0.01
orange	3.7 ± 0.2	2.6 ± 0.2	0.30 ± 0.02	0.64 ± 0.04	-	-
strawberry	3.8 ± 0.2	3.0 ± 0.2	0.31 ± 0.02	0.73 ± 0.05	0.28 ± 0.01	0.65 ± 0.02
plum	6.6 ± 0.5	3.9 ± 0.2	0.54 ± 0.04	0.96 ± 0.04	0.48 ± 0.01	0.90 ± 0.03
apple	6.9 ± 0.5	4.0 ± 0.2	0.56 ± 0.04	0.98 ± 0.06	0.49 ± 0.02	0.91 ± 0.03
tomatoes	2.7 ± 0.1	1.8 ± 0.1	0.22 ± 0.01	0.43 ± 0.02	0.23 ± 0.01	0.40 ± 0.01
green peas	3.2 ± 0.2	2.1 ± 0.1	0.26 ± 0.02	0.50 ± 0.03	0.25 ± 0.01	0.50 ± 0.01
potatoes	4.1 ± 0.2	2.5 ± 0.2	0.33 ± 0.02	0.62 ± 0.04	0.33 ± 0.01	0.58 ± 0.02
carrot	4.2 ± 0.2	2.6 ± 0.2	0.34 ± 0.02	0.64 ± 0.04	0.32 ± 0.01	0.61 ± 0.02
courgette	4.4 ± 0.2	2.8 ± 0.2	0.36 ± 0.02	0.67 ± 0.04	0.34 ± 0.01	0.64 ± 0.02
cucumber	7.0 ± 0.5	4.0 ± 0.2	0.57 ± 0.04	0.97 ± 0.06	0.51 ± 0.02	0.96 ± 0.03
wheat	3.2 ± 0.1	2.7 ± 0.2	0.26 ± 0.01	0.65 ± 0.04	0.25 ± 0.01	0.62 ± 0.02
barley	3.6 ± 0.2	2.5 ± 0.2	0.29 ± 0.02	0.62 ± 0.04	0.27 ± 0.01	0.57 ± 0.02
string bean	4.1 ± 0.2	2.6 ± 0.2	0.33 ± 0.02	0.63 ± 0.04	0.30 ± 0.01	0.62 ± 0.02
milk	3.6 ± 0.2	2.9 ± 0.2	0.29 ± 0.02	0.70 ± 0.04	-	-
olive oil	3.8 ± 0.2	2.8 ± 0.2	0.31 ± 0.02	0.69± 0.04	-	-
honey	4.1 ± 0.2	2.6 ± 0.2	0.33 ± 0.02	0.64 ± 0.04	-	-

According to UNSCEAR (2000a) wide ranges for uranium and thorium concentrations in foods were reported for different countries reflecting all kinds of soils on which plants grow (Tab. II).

A census of the food consumption (1825 families corresponding to 3865 adults, 1767 children belonging to the 2–7 years age group, 1879 children belonging to the 7–12 years age group and 2118 teenagers belonging to the 12–17 years age group) for the urban population in major cities in Morocco was taken to determine food intake masses. Data obtained are shown in Table III.

The total ^{238}U and ^{232}Th intakes depend on the eating habits of the population (food intake masses, category of food) and on the ^{238}U and ^{232}Th concentrations of foodstuffs which depend on the nature of soils on which those plants grow as well as on the nature of the plant tissue (Misdaq and Bourzik, 2002). It is to be noted from data shown in Table III that cereals are the big contributors to the annual dietary intakes of ^{238}U (38 to 46%) and ^{232}Th (41 to 50%) for teenagers (12–17 years) and adults members of the Moroccan population whereas milk is the major contributor to the annual intakes of ^{238}U (36 to 42%) and ^{232}Th (38 to 45%) for the 2–7 years and 7–12 years children. This is because consumption rates of cereals and milk are higher than those of the other food materials for these age groups of the Moroccan population (Tab. III). In the USA, fishes and shellfishes (38%), cereals, excluding rice (25.6%) and vegetables (24.4%) are the big contributors to the annual intake of ^{238}U by adults, while vegetables (64.8%), grains (16.8%) and animal and fish products (13.7%) are the main contributors to the annual intake of ^{232}Th (Fisenne *et al.*, 1987). In Japan, two food groups, seaweeds (49.6%) and fishes and shellfishes (25.8%), are big contributors to dietary ^{238}U intake whereas the group of fishes and shellfishes (44.3%) is the biggest contributor to the annual of ^{232}Th intake (Shiraishi *et al.*, 2000).

3.2. *Committed equivalent doses due to ^{238}U and ^{232}Th in different compartments of the human body from the ingestion of various food materials*

Annual committed equivalent doses due to uranium ($H_T(U)$) and thorium ($H_T(Th)$) have been evaluated in the human body organs and tissues from the ingestion of a typical food basket composed of banana, orange, strawberry, apple, tomato, green pea, potato, carrot, courgette, cucumber, wheat, barley, string bean, milk, olive oil and honey by Moroccan members of the public by using equations (3) and (4). Data obtained are shown in Table IV. From the standard deviation of the intake mass determination and statistical relative uncertainty of the ^{238}U and ^{232}Th concentration determination one can evaluate the uncertainty of the committed equivalent dose determination which is estimated to be about 10%.

TABLE II

Ranges of the ^{238}U and ^{232}Th concentrations in foods in different countries (UNSCEAR, 2000a).
Intervalles de variation des concentrations en ^{238}U et en ^{232}Th des aliments dans différents pays (UNSCEAR, 2000a).

Country	Milk products		Leafy vegetables		Grain products		Root vegetables and fruits	
	$A_c(^{238}U)$ (mBq kg^{-1})	$A_c(^{232}Th)$ (mBq kg^{-1})	$A_c(^{238}U)$ (mBq kg^{-1})	$A_c(^{232}Th)$ (mBq kg^{-1})	$A_c(^{238}U)$ (mBq kg^{-1})	$A_c(^{232}Th)$ (mBq kg^{-1})	$A_c(^{238}U)$ (mBq kg^{-1})	$A_c(^{232}Th)$ (mBq kg^{-1})
United states	0.7	0.27	24	18	3–23	0.1–2.8	0.9–7.7	0.08–1.4
China	13	1.2	16	23	9.8	13	13	4.7
India	17	-	61–72	-	7.4–67	-	0.4–77	-
Japan	0.55	0.29	-	-	1.2	1.2	26	2.3
Germany	-	-	6–2200	-	20–400	-	10–2900	-
Poland	2.6	1.2	14–15	4–7	4.7–11	2.0-21	0.9–10	0.7–7.1
Romania	-	-	-	-	6.1–85	1.6–33	6–120	0.4–2.1
United Kingdom	0.1–4.9	-	9.8–400	-	6.2–35	12	6	-
Morocco	3.6	2.9	2.7–7.0	1.8–4.0	3.2–4.1	2.5–2.7	3.4–6.9	2.2–4.0

TABLE III

Data obtained for the annual uranium (I_U) and thorium (I_{Th}) intakes from the ingestion of various foodstuffs by individuals belonging to different age groups of the Moroccan population.

Résultats obtenus pour les incorporations annuelles en uranium (I_U) et en thorium (I_{Th}) suite à l'ingestion de divers aliments par différents groupes d'âge de la population marocaine.

Food material sample	2-7 years age group			7-12 years age group			12-17 years age group			Adults (>17 years)		
	Intake mass (kg y^{-1})	I_U (mBq y^{-1})	I_{Th} (mBq y^{-1})	Intake mass (kg y^{-1})	I_U (mBq y^{-1})	I_{Th} (mBq y^{-1})	Intake mass (kg y^{-1})	I_U (mBq y^{-1})	I_{Th} (mBq y^{-1})	Intake mass (kg y^{-1})	I_U (mBq y^{-1})	I_{Th} (mBq y^{-1})
banana	5.0 ± 0.2	17 ± 1	11 ± 1	5.0 ± 0.2	17 ± 1	11 ± 1	4.0 ± 0.1	13.8 ± 0.8	8.8 ± 0.6	4.0 ± 0.1	13.8 ± 0.8	8.9 ± 0.6
orange	8.0 ± 0.3	29 ± 2	21 ± 2	8.0 ± 0.3	29 ± 2	21 ± 2	8.0 ± 0.3	29 ± 2	21 ± 1	8.0 ± 0.3	29 ± 2	21 ± 1
strawberry	1.00 ± 0.02	3.8 ± 0.3	3.0 ± 0.2	1.00 ± 0.02	3.8 ± 0.3	3.0 ± 0.2	2.00 ± 0.06	7.6 ± 0.5	6 ± 0.4	2.00 ± 0.06	7.6 ± 0.5	6.0 ± 0.4
plum	1.00 ± 0.02	6.6 ± 0.5	3.9 ± 0.2	1.00 ± 0.02	6.6 ± 0.5	3.9 ± 0.2	2.00 ± 0.05	13.0 ± 0.8	7.9 ± 0.5	2.00 ± 0.05	13 ± 1	7.9 ± 0.5
apple	4.5 ± 0.1	31 ± 2	18 ± 1	4.0 ± 0.1	27 ± 2	16 ± 1	3.0 ± 0.1	21 ± 1	12 ± 0.8	3.0 ± 0.1	21 ± 1	12 ± 1
tomatoes	6.0 ± 0.2	16 ± 1	10.6 ± 0.8	7.0 ± 0.2	19 ± 1	12.4 ± 0.9	7.0 ± 0.2	19 ± 1	12.4 ± 0.9	9.0 ± 0.2	24 ± 2	16 ± 1
green peas	2.50 ± 0.05	8.0 ± 0.4	5.1 ± 0.3	4.0 ± 0.1	12.8 ± 0.8	8.2 ± 0.5	5.0 ± 0.2	16 ± 1	10.3 ± 0.7	9.0 ± 0.3	29 ± 2	18 ± 1
potatoes	7.0 ± 0.2	28 ± 2	18 ± 1	8.0 ± 0.2	32 ± 2	20 ± 1	10.0 ± 0.3	41 ± 2	25 ± 1	15.0 ± 0.5	61 ± 4	38 ± 2
carrot	3.0 ± 0.1	12.5 ± 0.7	7.9 ± 0.5	4.0 ± 0.2	17 ± 1	10.5 ± 0.7	4.0 ± 0.2	17 ± 1	10.5 ± 0.8	6.0 ± 0.3	25 ± 2	16 ± 1
courgette	0.50 ± 0.01	2.2 ± 0.1	1.37 ± 0.08	0.5 ± 0.01	2.2 ± 0.2	1.4 ± 0.1	1.00 ± 0.02	4.4 ± 0.3	2.7 ± 0.2	2.0 ± 0.05	8.9 ± 0.6	5.5 ± 0.3
cucumber	0.50 ± 0.01	3.5 ± 0.2	2.0 ± 0.1	0.5 ± 0.01	3.5 ± 0.2	2.0 ± 0.1	1.00 ± 0.03	7.0 ± 0.4	4.0 ± 0.2	1.00 ± 0.03	7.0 ± 0.4	4.0 ± 0.2
wheat	30.5 ± 0.8	96 ± 6	80 ± 5	40 ± 1	127 ± 8	107 ± 7	60 ± 2	192 ± 13	160 ± 10	85 ± 3	271 ± 18	227 ± 15
barley	1.00 ± 0.02	3.5 ± 0.2	2.5 ± 0.1	2.00 ± 0.05	7.1 ± 0.4	5.1 ± 0.3	6.0 ± 0.1	21 ± 1	15 ± 1	10.0 ± 0.2	36 ± 2	25 ± 2
string bean	4.0 ± 0.1	16.2 ± 0.9	10.3 ± 0.7	5.0 ± 0.2	20 ± 1	12.9 ± 0.8	5.0 ± 0.1	20 ± 1	12.9 ± 0.8	10.0 ± 0.2	41 ± 2	26 ± 2
milk	56.0 ± 3.5	199 ± 14	161 ± 11	52 ± 3	185 ± 17	149 ± 9	50.0 ± 1.2	178 ± 10	144 ± 10	40 ± 1	142 ± 8	115 ± 7
olive oil	1.00 ± 0.02	3.8 ± 0.2	2.8 ± 0.8	2.00 ± 0.06	7.6 ± 0.4	5.6 ± 0.3	3.00 ± 0.01	11.4 ± 0.4	8.5 ± 0.4	5.5 ± 0.01	21 ± 1	15.7 ± 0.8
honey	0.1 ± 0.005	0.40 ± 0.03	0.26 ± 0.01	0.20 ± 0.01	0.81 ± 0.05	0.52 ± 0.03	0.20 ± 0.01	0.81 ± 0.05	0.52 ± 0.04	0.25 ± 0.02	1.0 ± 0.8	0.70 ± 0.05

TABLE IV

Data obtained for the annual committed equivalent doses due to ^{238}U (H_T(U)) and ^{232}Th (H_T(Th)) in different organs and tissues of the human body from the ingestion of a typical food basket by individuals belonging to different age groups of the Moroccan population.

Résultats obtenus pour les les équivalents de dose engagée dus à l'^{238}U (H_T(U)) et au ^{232}Th (H_T(Th)) dans différents organes et tissus humains suite à l'ingestion d'une corbeille alimentaire typique par différents groupes d'âge de la population marocaine.

Tissue	2–7 years age group		7–12 years age group		12–17 years age group		Adults (>17 years)	
	H_T(U) (10^{-8} Sv)	H_T(Th) (10^{-8} Sv)	H_T(U) (10^{-8} Sv)	H_T(Th) (10^{-8} Sv)	H_T(U) (10^{-8} Sv)	H_T(Th) (10^{-8} Sv)	H_T(U) (10^{-8} Sv)	H_T(Th) (10^{-8} Sv)
Liver	7.7 ± 0.7	12 ± 1	6.3 ± 0.5	9.8 ± 0.8	6.2 ± 0.4	9.8 ± 0.8	7.3 ± 0.5	10.2 ± 0.8
Kidney	27 ± 2	12 ± 1	20 ± 1	9.8 ± 0.8	18 ± 1	9.3 ± 0.7	19 ± 1	10.2 ± 0.8
Bone surfaces	58 ± 5	471 ± 40	73 ± 6	471 ± 37	129 ± 10	557 ± 44	54 ± 4	679 ± 54
Red marrow	5.8 ± 0.5	34 ± 3	5.8 ± 0.5	27 ± 2	8.0 ± 0.6	25 ± 2	5.7 ± 0.4	26 ± 2
Testes	2.1 ± 0.1	6.9 ± 0.5	1.8 ± 0.1	5.9 ± 0.5	1.7 ± 0.1	6.5 ± 0.5	1.9 ± 0.1	5.7 ± 0.5
Ovaries	1.9 ± 0.1	7.2 ± 0.6	1.7 ± 0.1	6.3 ± 0.5	1.6 ± 0.1	6.5 ± 0.5	1.9 ± 0.1	5.7 ± 0.5
Bladder	1.9 ± 0.1	2.5 ± 0.2	1.6 ± 0.1	2.1 ± 0.1	1.7 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	2.0 ± 0.1
Stomach	2.1 ± 0.1	2.6 ± 0.2	1.7 ± 0.1	2.1 ± 0.1	1.7 ± 0.1	2.0 ± 0.1	2.0 ± 0.1	2.1 ± 0.1
Small intestine	2.4 ± 0.1	2.9 ± 0.2	1.9 ± 0.1	2.3 ± 0.1	1.8 ± 0.1	2.0 ± 0.1	2.0 ± 0.1	2.1 ± 0.1
Upper large intestine	4.6 ± 0.4	4.7 ± 0.4	3.4 ± 0.3	3.4 ± 0.2	2.8 ± 0.2	2.8 ± 0.2	2.9 ± 0.2	2.9 ± 0.2
Lower large intestine	10.1 ± 0.9	8.3 ± 0.7	6.8 ± 0.6	5.9 ± 0.4	5.0 ± 04	4.5 ± 0.4	5.2 ± 0.4	4.5 ± 0.4
Annual effective dose (10^{-8} Sv)	4.7	14	4.1	11	4.6	12	3.8	13

TABLE V

Values of the ingestion dose coefficients for the ^{238}U (h_T(U)) and ^{232}Th (h_T(Th)) radionuclides in different organs and tissues of the human body of individuals belonging to the 2–7 years, 7–12 years, 12–17 years and adults age groups (ICRP, 1995).

Valeurs des coefficients de dose par ingestion des radionucléides ^{238}U (h_T(U)) et ^{232}Th (h_T(Th)) pour différents organes et tissus des individus des groupes d'âge 2–7 ans, 7–12 ans, 12–17 ans et adultes (ICRP, 1995).

	2–7 years age group		7–12 years age group		12–17 years age group		Adults (>17 years)	
Tissue	$h_T(^{238}U)$ (10^{-8} Sv Bq^{-1})	$h_T(^{232}Th)$ (10^{-8} Sv Bq^{-1})	$h_T(^{238}U)$ (10^{-8} Sv)	$h_T(^{232}Th)$ (10^{-8} Sv)	$h_T(^{238}U)$ (10^{-8} Sv)	$h_T(^{232}Th)$ (10^{-8} Sv)	$h_T(^{238}U)$ (10^{-8} Sv)	$h_T(^{232}Th)$ (10^{-8} Sv)
Liver	16	34	12	25	10	21	9.6	18
Kidney	56	33	39	25	29	20	25	18
Bone surfaces	120	1300	140	1200	210	1200	71	1200
Red marrow	12	94	11	68	13	54	7.5	46
Testes	4.3	19	3.5	15	2.7	14	2.5	10
Ovaries	4	20	3.2	16	2.6	14	2.5	10
Bladder	4	7	3.1	5.3	2.7	4.1	2.5	3.6
Stomach	4.3	7.3	3.3	5.4	2.8	4.3	2.6	3.7
Small intestine	4.9	7.9	3.7	5.8	2.9	4.4	2.7	3.8
Upper large intestine	9.6	13	6.5	8.6	4.5	6	3.9	5.1
Lower large intestine	21	23	13	15	8.2	9.6	6.9	8

We notice from results shown in Table IV that committed equivalent doses due to ^{238}U and ^{232}Th from the ingestion of the considered typical food basket by Moroccan consumers are clearly higher in the bone surfaces than in the other organs. This is due to the fact that bone surfaces show larger ingestion dose coefficients for ^{238}U and ^{238}Th than the other compartments of the human body (Tab. V) because these elements are bone seekers. Even though the ^{238}U intakes are larger than the ^{232}Th ones, committed equivalent doses due to ^{238}U in the bone surfaces are smaller than those due to ^{232}Th for adult consumers. This is due to the fact that bone surfaces show higher ingestion dose coefficients for thorium than for uranium.

A global committed effective dose due to ^{238}U and ^{232}Th originated from the intake of the studied foodstuffs was evaluated for the members of the public. The maximum value was found to be equal to 0.19 μSv y^{-1} (for 2–7 years age group) which is smaller than the mean world values for ingestion of foodstuffs and water (ranging from 0.2 to 0.8 mSv y^{-1}) (UNSCEAR, 2000b).

4. Conclusion

It is concluded that CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) are useful to determine the uranium and thorium intakes from the ingestion of a typical food basket by individuals belonging to different age groups of the Moroccan population. It has been shown that cereals and milk are the largest contributors to the ^{238}U and ^{232}Th dietary intakes for different age groups of individuals in Morocco. Annual committed equivalent doses due to ^{238}U and ^{232}Th from the ingestion of a typical food basket by the Moroccan population depend on the intakes of these radionuclides as well as their corresponding ingestion dose coefficients. It has been shown that the resulting global committed effective dose still lower than the mean world values for ingestion.

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