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Annual Committed Effective Dose from Various Phytotherapeutic Preparations (due to ^{238}U, ^{232}Th, ^{222}Rn and ^{220}Rn) Estimated for Adult Moroccan Patients

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Abstract

We use a nuclear technique based on the determination of the detection efficiencies of solid state nuclear track detectors CR-39 and LR-115 type II (SSNTDs) for alpha particles emitted from the series of uranium-238 and thorium-232 in a phytotherapeutic sample and the measurement of alpha track densities registered on these detectors to assess alpha activities due to uranium-238; thorium-232; radon and thoron in samples of phytotherapeutic preparations consumed by Moroccan adult patients. For modern preparations, the alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn range from 14.27 mBq/kg to 22.02 mBq/kg, from 6.27 mBq/kg to 9.64 mBq/kg and from 14.27 Bq/kg to 22.02 Bq/kg respectively. For classical preparations, the alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn range from 16.73 mBq/kg to 24 mBq/kg, from 7.34 mBq/kg to 10.82 mBq/kg and from 16.73 Bq/kg to 24.72 Bq/kg respectively. A dosimetric model for ingestion has been highlighted to determine committed equivalent dose to different compartments of human gastrointestinal system due to the ingestion of phytotherapeutic preparations by Moroccan adult patients. The maximum overall effective dose due to ^{238}U, ^{232}Th, and ^{222}Rn after the ingestion of the studied phytotherapeutic preparations, was found equal to 38×10^{-8} $S{\cdot}vy^{-1}$ which is less than the dose limit given by the international commission for radiological protection in it publication 56.

Keywords

SSNTD, Uranium, Thorium, Radon and Thoron Concentrations, Phytotherapeutic Preparations, Committed Equivalent Doses, Patients

1. Introduction

Phytotherapy is the treatment of diseases by plants. The use of medicinal plants is both the oldest and the most modern therapeutic [1].

According to the World Health Organization (WHO), in some developing countries in Asia, Africa and Latin America, 80% of the population uses traditional medicine mainly in rural areas [2].

In Morocco, phytotherapy is an ancient practice. Empirical knowledge has been passed down orally through the generations and enriched thanks to the strategic geographical situation of Morocco (bioclimatic diversity and civilizations brewing through history) [3].

Morocco possesses a wealth of plants with about 42,000 species of which nearly 600 are used in traditional medicine [2].

We observe that in most Moroccan homes, instead of taking pharmaceutical medicines, people prefer to use medicinal plants among which we distinguish: White sagebrush (Chih), Garlic, Thyme (Zaatar), black cumin…[4].

The results of a study by Dr. M. Hmamouchi and all on the use of plants in traditional Moroccan medicine show that [5]:

70% - 80% of respondents use medicinal plants for treatment.

The presence of medicinal plants is in most homes. This is affirmed by 80% of the people making up the elude sample.

The economic reasons are most often behind the use of this therapeutic means. Indeed, 56.5% of individuals using this medicine in the elude sample state that traditional medicine is less expensive.

According to these results, we note that most Moroccans give themselves to phytotherapy and there are two types:

Classical phytotherapy: a traditional practice, sometimes very old based on the use of plants according to the virtues discovered empirically.

Modern phytotherapy: a practice based on scientific advances that seeks active plant extracts.

Based on these results, we notice that most Moroccans have resort to traditional herbal medicine. Hence, it is the importance of this study. Especially, we have treated the side of natural radioactivity that is due to the presence of natural radioelements ^{238}U, ^{232}Th, ^{222}Rn and ^{220}Rn in the medicinal plants.

Natural radioactivity is introduced into the human body primarily through the ingestion of natural radioelements and their progeny: potassium 40 K and series of uranium ^{238}U and thorium ^{232}Th and by inhalation of radon and thoron gases and their offspring, but with a lesser degree [6] [7].

Natural radioelements have existed since the creation of the earth. They are found in soils, waters and rocks. These natural radioelements and their offspring are transferred via water to medicinal plants that are ingested by patients.

It is therefore necessary to measure the concentrations of radioelements present in the samples of phytotherapeutic preparations, to estimate the resulting dose and whether it is necessary to take action to avoid patient exposure to radiation

[8].

The presence of radon isotopes in the environment results from the decay of radioactive elements (uranium-238, uranium-235 and thorium-232). Radon, a naturally occurring gas that comes from the soil, is odourless, colourless and radioactive. It is soluble in water and is present in all materials all over the world.

In this work, we used CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) to measure uranium, thorium, radon and thoron concentrations in various phytotherapeutic preparations. We also determined annual committed equivalent doses from intakes of ^{238}U, ^{232}Th and ^{222}Rn in different compartments of the human body of the Moroccan patients from the ingestion of various phytotherapeutic preparations.

2. Materials and Methods

2.1. Description of Samples Studied—Amount Consumed

Several phytotherapists were contacted to select the samples of our study, and thanks to a statistical study, 20 of the most consumed preparations by adult Moroccan patients were selected, but from two different sources: classical phytotherapists (10) and modern phytotherapists (10) (see Table 1, Table 2).

In order to calculate the annual amount consumed by an adult patient, a statistical study was carried out with the help of phytotherapists; the results are given in Table 3.

Table 1. Description of the modern phytotherapeutic preparations studied.

Modern Phytotherapeutic Preparations	Basic components	Properties
MPP1	Nigella - Cress - Fenugreek - Bean - Flaxseed…	Antiseptic effect of lung infections
MPP2	Lavender - Corn Stigmata - Saxifrage…	Anti-inflammatory effect of urinary tract infections
MPP3	Ginger - Cloves - Sesame - Cinnamon…	It is a sexual tonic/aphrodisiac
MPP4	Thyme - Carob - Pomegranate Skin…	Use for stomach problems such as diarrhea
MPP5	Anise - Carvis - Macis - Coriander - Flaxseed…	Use to promote intestinal transit
MPP6	Ginger - Cinnamon - Rosemary - Lavender - Nigella - Watercress - White Pepper…	Use to relieve rheumatism
MPP7	Rose - Nigella - Cassia Italica…	Use for the treatment of hemorrhoids to cure constipation
MPP8	Carob - Pomegranate peel - Basil…	Use for stomach problems such as diarrhea
MPP9	Anise - Sagebrush - Rosemary…	Antiseptic effect of intestinal infections
MPP10	Madder - Turmeric - Fenugreek…	Diuretic, choleretic, laxative, astringent

Table 2. Description of the classical phytotherapeutic preparations studied.

Classical Phytotherapeutic Preparations	Basic components	Properties
CPP1	Nigella - Cress - Fenugreek - Bean - Flaxseed…	Antiseptic effect of lung infections
CPP2	Lavender - Corn Stigmata - Saxifrage…	Anti-inflammatory effect of urinary tract infections
CPP3	Ginger - Cloves - Sesame - Cinnamon…	It is a sexual tonic/aphrodisiac
CPP4	Thyme - Carob - Pomegranate Skin…	Use for stomach problems such as diarrhea
CPP5	Anise - Carvis - Macis - Coriander - Flaxseed…	Use to promote intestinal transit
CPP6	Ginger - Cinnamon - Rosemary - Lavender - Nigella - Watercress - White Pepper…	Use to relieve rheumatism
CPP7	Rose - Nigella - Cassia Italica…	Use for the treatment of hemorrhoids to cure constipation
CPP8	Carob - Pomegranate peel - Basil…	Use for stomach problems such as diarrhea
CPP9	Anise - Sagebrush - Rosemary…	Antiseptic effect of intestinal infections
CPP10	Madder - Turmeric - Fenugreek…	Diuretic, choleretic, laxative, astringent

Table 3. The annual amount ingested by patients of each phytotherapeutic preparation.

Modern Phytotherapeutic Preparations	Ingested mass (Kg/yr)	Classical Phytotherapeutic Preparations	Ingested mass (Kg/yr)
MPP1	20 ± 1	**CPP1**	20 ± 1
MPP2	20 ± 1	**CPP2**	20 ± 1
MPP3	27 ± 2	**CPP3**	27 ± 2
MPP4	14 ± 1	**CPP4**	14 ± 1
MPP5	27 ± 2	**CPP5**	27 ± 2
MPP6	27 ± 2	**CPP6**	27 ± 2
MPP7	2.7 ± 0.2	**CPP7**	2.7 ± 0.2
MPP8	2.7 ± 0.16	**CPP8**	2.7 ± 0.16
MPP9	20 ± 1	**CPP9**	20 ± 1
MPP10	27 ± 2	**CPP10**	27 ± 2

2.2. Experimental Method

In a well-sealed plastic capsule, 4 cm in diameter and 1cm in height, samples of various phytotherapeutic preparations (classical and modern) consumed by adult patients in Morocco in direct contact with detectors CR-39 and LR-115 type II (see Figure 1) for 30 days. The closed capsule is placed in a room at ambient temperature and pressure. During this exposure time the alpha particles emitted by uranium-238, thorium-232 and their respective descendants bombard the SSNTD. After irradiation, the SSNTD is developed in soda solution (NaOH) under appropriate conditions [9]. After this chemical treatment, the trace densities recorded on the CR-39 and LR-115 II films were counted using an ordinary optical microscope.

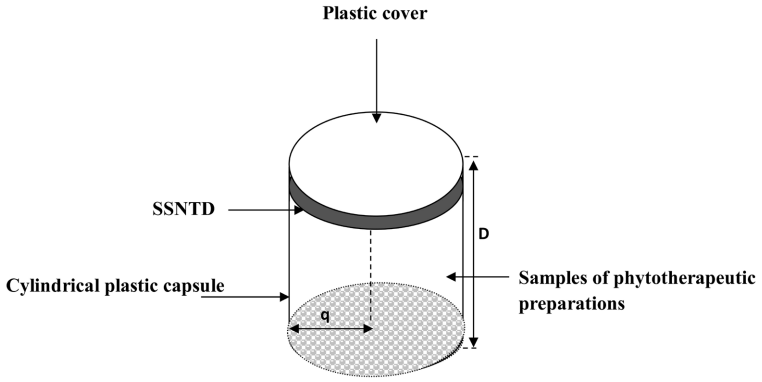

Figure 1. Experimental device for the detection of alpha particles by SSNTD, D = 1 cm and q = 2 cm.

Since the irradiation cell is well closed, there is no exhaust of gas (radon and thoron) and the exposure time is 30 days, we assume radioactive secular equilibrium between uranium-238 and each of its decay products and between thorium-232 and each of its progeny. For our experimental conditions, the residual thickness of LR-115 type II is 5 μm corresponding to the minimum energy limits ($E_{\min}$ = 1.6 MeV) and the maximum energy ($E_{\max}$ = 4.7 MeV) for alpha particles to be recorded in SSNTD LR-115 type II [10]. All alpha particles emitted from the uranium and thorium series that reach the LR-115 detector at an angle below the critical angle of revelation θ_c' with a residual energy between the limits mentioned above are registered as bright track-holes. Unlike the LR-115, the CR-39 is sensitive to particles of energy between 0 and 20 MeV alpha reach its surface at an angle below the critical angle of revelation θ_c. The angles of etching θ_c' and θ_c were calculated by using a method developed by Misdaq *et al.* [11]. The global track density rates (tracks·cm^{-2}·s^{-1}) due to alpha-particles emitted by the uranium-238 and thorium-232 series inside preparation sample and registered on the CR-39 and LR-115 II detectors, after subtracting the corresponding backgrounds, are given respectively by [12]:

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

And

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

where

q (cm) is the radius of the plastic container;

d_S is the density of the fish sample (g·cm^{-3});

S_d (cm^2) and S_d' (cm^2) are, respectively, the surface areas of the CR-39 and LR-115 II films;

$C(^{238}\mathrm{U})$ (ppm) and $C(^{232}\mathrm{Th})$ (ppm) are the uranium and thorium concentrations of the preparation sample;

$A_U(\text{Bq}\cdot\text{g}^{-1})$ = 0.0123 and $A_{Th}(\text{Bq}\cdot\text{g}^{-1})$ = 0.0041 are the specific activities of a sample for a ^{238}U content of 1 ppm; and a ^{232}Th content of 1 ppm;

R_j (cm) and R'_j (cm) are the ranges in the preparation sample of an alpha-particle of index j and initial energy E_j emitted by the nuclei of the uranium and thorium series, respectively;

k_j and k'_j are, respectively, the branching ratios corresponding to the disintegration of the nuclei of the uranium and thorium series;

ε_j^{CR}, $\varepsilon_j'^{CR}$, ε_j^{LR} and $\varepsilon_j'^{LR}$ are, respectively, the detection efficiencies of the CR-39 and LR-115 II detectors for the emitted alpha-particles emitted by the two families of ^{238}U and ^{232}Th.

The ranges of the emitted alpha-particles in the samples and SSNTDs were calculated by using a TRIM (Transport of Ions in Materials) program (Biersack and Ziegler 1998) [13].

This operation has been repeated ten times: the track densities recorded on the CR-39 and LR-115 II are almost identical within statistical errors.

By combining Equations (1) and (2), we obtain a relationship between global track densities and the ratio of thorium contents to uranium contents, for a phytotherapeutic sample. Indeed, we have:

$$\frac{C(\text{Th})}{C(\text{U})} = \frac{A_U}{A_{Th}} \frac{\left(\frac{S'_d}{S_d}\right)\sum_{j=1}^{8} k_j \varepsilon_j^{CR} R_j - \left(\frac{\rho_G^{CR}}{\rho_G^{LR}}\right)\sum_{j=1}^{8} k_j \varepsilon_j^{LR} R'_j}{\left(\frac{\rho_G^{CR}}{\rho_G^{LR}}\right)\sum_{j=1}^{7} k_j \varepsilon_j^{CR} R_j - \left(\frac{S'_d}{S_d}\right)\sum_{j=1}^{7} k_j \varepsilon_j^{LR} R'_j} \tag{3}$$

and

$$C(\text{U}) = \frac{2S'_d \rho_G^{LR}}{d_s \pi q^2 \left[A_U \sum_{j=1}^{8} k_j \varepsilon_j^{LR} R'_j + \left(\frac{C(\text{Th})}{C(\text{U})}\right) A_{Th} \sum_{j=1}^{7} k_j \varepsilon_j^{LR} R'_j \right]} \tag{4}$$

By calculating the detection efficiencies of the solid nuclear trace detectors CR-39 (ε_j^{CR}, $\varepsilon_j'^{CR}$) and LR-115 type II (ε_j^{LR}, $\varepsilon_j'^{LR}$) by means of the code "SSNTDEαM", and by counting the densities of traces recorded on the films (ρ_G^{CR}, ρ_G^{LR}) we can determine the ratio $\frac{C(\text{Th})}{C(\text{U})}$ and then the uranium and thorium contents in the samples studied.

The alpha activities due to radon ($A_c(^{222}\text{Rn})$) and thoron ($A_c(^{220}\text{Rn})$) (Bq/l) are determined in the samples considered using a method described in detail by Misdaq *et al.* [12].

Trace densities, due to alpha particles emitted by the uranium series and the thorium series, recorded on the films CR-39 (ρ_G^{CR}) and LR-115 type II (ρ_G^{LR}) are given by:

$$\rho_G^{CR} = \frac{\pi q^2}{2S_d} \left[A_c\left(^{222}\text{Rn}\right) \sum_{j=1}^{8} k_j R_j \varepsilon_j^{CR} + A_c\left(^{220}\text{Rn}\right) \sum_{j=1}^{7} k'_j R'_j \varepsilon_j'^{CR} \right] \tag{5}$$

and

$$\rho_G^{LR} = \frac{\pi q^2}{2S'_d}\left[A_c\left({}^{222}\mathrm{Rn}\right)\sum_{j=1}^{8} k_j R_j \varepsilon_j^{LR} + A_c\left({}^{220}\mathrm{Rn}\right)\sum_{j=1}^{7} k'_j R'_j \varepsilon'^{LR}_j \right] \quad (6)$$

By combining the Equations (5) and (6), we obtain the relationship between track densities and the ratio of alpha-radon to thoron and radon activity in the phytotherapeutic sample studied, we have:

$$\frac{A_c^{220}}{A_c^{222}} = \frac{\frac{S'_d}{S_d}\sum_{j=1}^{8} k_j \varepsilon_j^{CR} R_j - \frac{\rho_G^{CR}}{\rho_G^{LR}}\sum_{j=1}^{8} k_j \varepsilon_j^{LR} R_j}{\frac{\rho_G^{CR}}{\rho_G^{LR}}\sum_{j=1}^{7} k_j \varepsilon'^{CR}_j R_j - \frac{S'_d}{S_d}\sum_{j=1}^{7} k_j \varepsilon'^{LR}_j R_j} \quad (7)$$

and

$$A_c^{222} = \frac{2S'_d \rho_G^{LR}}{\pi q^2 d_s\left[\sum_{j=1}^{8} k_j \varepsilon_j^{LR} R_j + \frac{A_c^{220}}{A_c^{222}}\sum_{j=1}^{7} k_j \varepsilon'^{LR}_j R_j\right]} \quad (8)$$

By measuring the alpha activities due to radon and thoron, it is possible to assess the annual intake of radon and thoron following ingestion of phytotherapeutic preparations consumed by a Moroccan adult.

2.3. Evaluation of Alpha Activities due to ^{238}U, ^{232}Th and ^{222}Rn in the Human Body of Adult Patients from the Ingestion of Various Phytotherapeutic Preparations

Alpha-activities of ^{238}U and ^{232}Th in the different compartments of the human body from the ingestion of various phytotherapeutic preparations by an adult consumer are obtained by solving the differential equation system representing the rates of change of these activities by using a Maple 8 code (Maple 9.5) [14], providing that at $t = 0$ these activities are equal to zero except in the stomach. Indeed, for the n^{th} compartment, one has (Misdaq and Elamyn 2006):

$$A_c^n(\mathrm{U}) = I_{\mathrm{U}} \sum_{l=1}^{18} a_l^n \exp\left(-\gamma_l^n t\right) \quad (9)$$

And

$$A_c^n(\mathrm{Th}) = I_{\mathrm{Th}} \sum_{l'=1}^{18} a_{l'}^n \exp\left(-\gamma_{l'}^n t\right) \quad (10)$$

where: I_{U}(Bq) and I_{Th}(Bq) are, respectively, the intakes of uranium and thorium following ingestion of a quantity of phytotherapeutic preparation by a patient for one year., a_l^n and $a_{l'}^n$ are constants and γ_l^n and $\gamma_{l'}^n$ are rate constants expressed in d^{-1},relative to the organ "n".

Assuming that all the ingested radon from various phytotherapeutic preparations appears in the stomach, the radon alpha-activity in a tissue T of the gastrointestinal tract is given by Misdaq and Chaouqi (2008):

$$A_c^T(\mathrm{Rn}) = I_{\mathrm{Rn}} \sum_{i=1}^{4} a_i^T \exp\left(-\gamma_i^T t\right) \quad (11)$$

where I_{Rn} (Bq) is the radon intake from the ingestion of a phytotherapeutic preparations sample, a_i^T is a constant, and γ_i^T is a rate constant expressed in h^{-1}.

2.4. Evaluation of Committed Dose Equivalents Due to ^{238}U, ^{232}Th and ^{222}Rn in the Human Body of Adult Patients from the Ingestion of Various Phytotherapeutic Preparations

These dose equivalents can be assessed using the following relationships:

$$H_T(\mathrm{U}) = I_{\mathrm{U}} h_T(\mathrm{U}) \tag{12}$$

$$H_T(\mathrm{Th}) = I_{\mathrm{Th}} h_T(\mathrm{Th}) \tag{13}$$

and

$$H_T(\mathrm{Rn}) = I_{\mathrm{Rn}} h_T(\mathrm{Rn}) \tag{14}$$

where,

I_{U}(Bq), I_{Th}(Bq) and I_{Rn}(Bq) are, respectively, the uranium, thorium and radon intakes from the ingestion of a various phytotherapeutic preparations by a patient for one year.

h_T(U) (Sv·Bq^{-1}), h_T(Th) (Sv·Bq^{-1}) et h_T(Rn) (Sv·Bq^{-1}) are the ingestion dose coefficients for the ^{238}U, ^{232}Th and ^{222}Rn radionuclides, respectively (ICRP 1995) [15].

The annual committed effective doses (Sv) for an individual due to ^{238}U, ^{232}Th and ^{222}Rn after ingestion of various phytotherapeutic preparations are given by:

$$E_{\mathrm{U}} = \sum_T W_T H_T(\mathrm{U}) \tag{15}$$

$$E_{\mathrm{Th}} = \sum_T W_T H_T(\mathrm{Th}) \tag{16}$$

And

$$E_{\mathrm{Rn}} = \sum_T W_T H_T(\mathrm{Rn}) \tag{17}$$

where:

W_T is the tissue weighting factor [16]. H_T(U), H_T(Th) and H_T(Rn) are committed dose equivalents due to incorporation of ^{238}U, ^{232}Th and ^{222}Rn into T-tissue or T-organ.

2.5. Results and Discussions

2.5.1. Concentrations of ^{238}U, ^{232}Th, ^{222}Rn and ^{220}Rn in Various Phytotherapeutic Preparations

Concentrations of uranium ($C(^{238}\mathrm{U})$) and thorium ($C(^{232}\mathrm{Th})$); and alpha activity per unit volume from radon $A_c(^{222}\mathrm{Rn})$, and thoron $A_c(^{220}\mathrm{Rn})$ were measured in various samples of phytotherapeutic preparations.

The results obtained are grouped in **Table 4** (modern phytotherapy) and **Table 5** (classical phytotherapy). The relative uncertainty in the determination of uranium, thorium, radon and thoron concentrations does not exceed 10%.

Based on the results given in **Table 4** and **Table 5**, all samples studied contain more thorium than uranium, (C(Th) is greater than C(U)), therefore for all phytotherapeutic preparations the alpha activities per unit volume due to radon $A_c(^{222}\mathrm{Rn})$ are higher than those due to thoron $A_c(^{220}\mathrm{Rn})$. This can be

explained by the fact that the soils where the medicinal plants that are the basis of these preparations grow contain more thorium than uranium.

The concentrations of ^{238}U, ^{232}Th and ^{222}Rn in classicall phytotherapeutic preparations are found to be higher than in modern phytotherapeutic preparations. This is due to the fact that classical preparations contain pollutant dust.

Table 4. Uranium ($C(^{238}U)$) and thorium ($C(^{232}Th)$) concentrations, and alpha activities per unit volume $A_c(^{222}Rn)$, and $A_c(^{220}Rn)$ in various samples of modern phytotherapeutic preparations.

Modern Phytotherapeutic Preparations	ρ_G^{LR} (10^{-5} tr·cm^{-2}·s^{-1})	ρ_G^{CR} (10^{-5} tr·cm^{-2}·s^{-1})	C(U) (ppm)	C(Th) (ppm)	A_c(U) (mBq·kg^{-1})	A_c(Th) (mBq·kg^{-1})	$A_c(^{222}Rn)$ (Bq·kg^{-1})	$A_c(^{220}Rn)$ (Bq·kg^{-1})
MPP1	5.80 ± 0.35	18.27 ± 1.10	1.59 ± 0.11	2.10 ± 0.15	19.56 ± 1.35	8.61 ± 0.62	19.56 ± 1.35	8.61 ± 0.62
MPP2	6.25 ± 0.38	19.69 ± 1.18	1.72 ± 0.12	2.25 ± 0.16	21.16 ± 1.48	9.23 ± 0.66	21.16 ± 1.48	9.23 ± 0.66
MPP3	4.71 ± 0.28	14.84 ± 0.89	1.30 ± 0.09	1.7 ± 0.12	15.99 ± 1.11	6.97 ± 0.49	15.99 ± 1.11	6.97 ± 0.49
MPP4	5.52 ± 0.33	17.39 ± 1.04	1.52 ± 0.11	1.99 ± 0.14	18.70 ± 1.35	8.16 ± 0.57	18.70 ± 1.35	8.16 ± 0.57
MPP5	4.96 ± 0.30	15.62 ± 0.94	1.36 ± 0.10	1.79 ± 0.13	16.73 ± 1.23	7.34 ± 0.53	16.73 ± 1.23	7.34 ± 0.53
MPP6	4.85 ± 0.29	15.28 ± 0.92	1.33 ± 0.09	1.75 ± 0.12	16.36 ± 1.11	7.18 ± 0.49	16.36 ± 1.11	7.18 ± 0.49
MPP7	4.23 ± 0.25	13.32 ± 0.80	1.16 ± 0.08	1.53 ± 0.11	14.27 ± 0.98	6.27 ± 0.45	14.27 ± 0.98	6.27 ± 0.45
MPP8	6.24 ± 0.37	19.66 ± 1.18	1.71 ± 0.12	2.25 ± 0.16	21.03 ± 1.48	9.23 ± 0.66	21.03 ± 1.48	9.23 ± 0.66
MPP9	6.51 ± 0.39	20.51 ± 1.23	1.79 ± 0.13	2.35 ± 0.16	22.02 ± 1.60	9.64 ± 0.66	22.02 ± 1.60	9.64 ± 0.66
MPP10	6.01 ± 0.36	18.93 ± 1.14	1.65 ± 0.12	2.17 ± 0.15	20.30 ± 1.48	8.90 ± 0.62	20.30 ± 1.48	8.90 ± 0.62

Table 5. Uranium ($C(^{238}U)$) and thorium ($C(^{232}Th)$) concentrations, and alpha activities per unit volume $A_c(^{222}Rn)$, and $A_c(^{220}Rn)$ in various samples of classical phytotherapeutic preparations.

Classical Phytotherapeutic Preparations	ρ_G^{LR} (10^{-5} tr·cm^{-2}·s^{-1})	ρ_G^{CR} (10^{-5} tr·cm^{-2}·s^{-1})	C(U) (ppm)	C(Th) (ppm)	A_c(U) (mBq·kg^{-1})	A_c(Th) (mBq·kg^{-1})	$A_c(^{222}Rn)$ (Bq·kg^{-1})	$A_c(^{220}Rn)$ (Bq·kg^{-1})
CPP1	6.52 ± 0.39	20.54 ± 1.23	1.79 ± 0.13	2.35 ± 0.16	22.02 ± 1.6	9.64 ± 0.66	22.02 ± 1.6	9.64 ± 0.66
CPP2	7.11 ± 0.43	22.4 ± 1.34	1.95 ± 0.14	2.57 ± 0.18	23.99 ± 1.72	10.54 ± 0.74	23.99 ± 1.72	10.54 ± 0.74
CPP3	5.15 ± 0.31	16.22 ± 0.97	1.41 ± 0.1	1.86 ± 0.13	17.34 ± 1.23	7.63 ± 0.53	17.34 ± 1.23	7.63 ± 0.53
CPP4	5.65 ± 0.34	17.8 ± 1.07	1.55 ± 0.11	2.04 ± 0.14	19.07 ± 1.35	8.36 ± 0.57	19.07 ± 1.35	8.36 ± 0.57
CPP5	5.87 ± 0.35	18.49 ± 1.11	1.61 ± 0.11	2.12 ± 0.15	19.8 ± 1.35	8.69 ± 0.61	19.8 ± 1.35	8.69 ± 0.61
CPP6	5.51 ± 0.33	17.36 ± 1.04	1.51 ± 0.11	1.99 ± 0.14	18.57 ± 1.35	8.16 ± 0.57	18.57 ± 1.35	8.16 ± 0.57
CPP7	4.97 ± 0.3	15.66 ± 0.94	1.36 ± 0.1	1.79 ± 0.13	16.73 ± 1.23	7.34 ± 0.53	16.73 ± 1.23	7.34 ± 0.53
CPP8	7.07 ± 0.42	22.27 ± 1.34	1.94 ± 0.14	2.55 ± 0.18	23.86 ± 1.72	10.46 ± 0.74	23.86 ± 1.72	10.46 ± 0.74
CPP9	7.31 ± 0.44	23.03 ± 1.38	2.01 ± 0.14	2.64 ± 0.18	24.72 ± 1.72	10.82 ± 0.74	24.72 ± 1.72	10.82 ± 0.74
CPP10	6.88 ± 0.41	21.67 ± 1.3	1.89 ± 0.13	2.48 ± 0.17	23.25 ± 1.6	10.17 ± 0.7	23.25 ± 1.6	10.17 ± 0.7

For modern preparations:

The minimum alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn are MPP7: (14.27 ± 0.98) mBq/kg, (6.27 ± 0.45) mBq/kg and (14.27 ± 0.98) Bq/kg, respectively.

The maximum alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn are MPP9: (22.02 ± 1.60) mBq/kg, (9.64 ± 0.66) mBq/kg and (22.02 ± 1.60) Bq/kg respectively.

For classical preparations:

The minimum alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn are MPP7: (16.73 ± 1.23) mBq/kg, (7.34 ± 0.53) mBq/kg and (16.73 ± 1.23) Bq/kg, respectively (Table 5).

The maximum alpha activities due to ^{238}U, ^{232}Th and ^{222}Rn are MPP9: (24.72 ± 1.72) mBq/kg, (10.82 ± 0.74) mBq/kg and (24.72 ± 1.72) Bq/kg respectively.

This is due to the nature of the basic medicinal plants of each preparation.

2.5.2. Intakes of ^{238}U, ^{232}Th and ^{222}Rn Following Ingestion of Phytotherapeutic Preparations by Adult Patients

Annual intakes of uranium $I(^{238}U)$, thorium $I(^{232}Th)$ and radon $I(^{222}Rn)$ for modern and classical phytotherapeutic preparations are given in Table 6(a) and Table 6(b), respectively.

Annual intakes of uranium $(I(^{238}U))(mBq{\cdot}yr^{-1})$, thorium$(I(^{232}Th))(mBq{\cdot}yr^{-1})$ and radon $(I(^{222}Rn))(Bq{\cdot}yr^{-1})$ in classical phytotherapeutic preparations are found to be higher than those in modern phytotherapeutic preparations. This is due to the fact that the concentrations of ^{238}U, ^{232}Th and ^{222}Rn in classical phytotherapeutic preparations are higher than those of modern phytotherapeutic preparations.

Table 6. (a). Annual intakes of uranium, thorium and radon in modern phytotherapeutic preparations. (b). Annual intakes of uranium, thorium and radon in classical phytotherapeutic preparations.

(a)

Classical Phytotherapeutic Preparations	$I(^{238}U)$ $(mBq{\cdot}yr^{-1})$	$I(^{232}Th)$ $(mBq{\cdot}yr^{-1})$	$I(^{222}Rn)$ $(Bq{\cdot}yr^{-1})$
CPP1	452 ± 36	198 ± 16	452 ± 36
CPP2	492 ± 39	216 ± 17	492 ± 39
CPP3	475 ± 38	209 ± 17	475 ± 38
CPP4	261 ± 21	114 ± 9	261 ± 21
CPP5	542 ± 43	238 ± 19	542 ± 43
CPP6	508 ± 41	223 ± 18	508 ± 41
CPP7	45 ± 4	20 ± 1.6	45 ± 4
CPP8	64 ± 5	28 ± 2	64 ± 5
CPP9	507 ± 41	222 ± 18	507 ± 41
CPP10	636 ± 51	278 ± 22	636 ± 51

(b)

Modern Phytotherapeutic Preparations	$I(^{238}U)$ (mBq·yr^{-1})	$I(^{232}Th)$ (mBq·yr^{-1})	$I(^{222}Rn)$ (Bq·yr^{-1})
MPP1	401 ± 32	177 ± 14	401 ± 32
MPP2	434 ± 35	189 ± 15	434 ± 35
MPP3	438 ± 35	191 ± 15	438 ± 35
MPP4	256 ± 20	112 ± 9	256 ± 20
MPP5	458 ± 37	201 ± 16	458 ± 37
MPP6	448 ± 36	196 ± 15	448 ± 36
MPP7	39 ± 3	17 ± 1	39 ± 3
MPP8	57 ± 5	25 ± 2	57 ± 5
MPP9	452 ± 36	198 ± 16	452 ± 36
MPP10	610 ± 49	244 ± 19	610 ± 49

For modern preparations, the annual intakes of uranium, thorium and radon by an adult patient range from (38.53 ± 3.08) mBq·yr^{-1} to (610.35 ± 48.83) mBq·yr^{-1}, from (16.93 ± 1.35) mBq·an^{-1} to (243.59 ± 19.49) mBq·yr^{-1} and from (38.53 ± 3.08) Bq·yr^{-1} to (610.35 ± 48.83) Bq·yr^{-1} respectively.

For classical preparations, the annual intakes of uranium, thorium and radon by an adult patient range from (45.17 ± 3.61) mBq·yr^{-1} to (636.35 ± 50.91) mBq·yr^{-1}, from (19.82 ± 1.59) mBq·yr^{-1} to (278.35 ± 22.27) mBq·yr^{-1} and from (45 ± 4) Bq·yr^{-1} to (636 ± 51) Bq·yr^{-1}, respectively.

Annual intakes vary according to the type of disease (chronic, transient…).

2.5.3. Committed Equivalent Doses due to ^{238}U, ^{232}Th and ^{222}Rn in Different Compartments of the Human Body from Ingestion of Various Phytotherapeutic Preparations by Adult Patients

Annual committed equivalent doses due to uranium 238 ($H_T(^{238}U)$), thorium 232 ($H_T(^{232}Th)$) and radon 222 ($H_T(^{222}Rn)$) from ingestion of various phytotherapeutic preparations by Moroccan adult patients were evaluated in different tissues and organs. The results obtained are illustrated in **Tables 7-12**. The relative uncertainty on the determination of committed equivalent doses is of the order of 10%.

The histograms in **Figure 2** represent committed dose equivalents due to ^{238}U, ^{232}Th and ^{222}Rn in different organs and tissues for Moroccan adults from ingestion of the MPP9 and CPP9.

From the results given in **Tables 7-12** and **Figures 2(a)-(c)**, it can be seen that:

It is to be noted from the results shown in **Tables 7-12** and **Figures 2(a)-(c)** that:

For all preparations the annual committed equivalent doses in the bone surfaces, due to the ^{238}U and ^{232}Th are superior to those in the other organs. This is due to the fact that the dose coefficients for bone surfaces for radionuclides ^{238}U and ^{232}Th are higher than for other compartments.

Even if the annual intakes in ^{238}U are higher than those in ^{232}Th, annual committed equivalent doses due to uranium 238 ($H_T(^{238}U)$), in bone surfaces, are lower than those due to thorium 232 ($H_T(^{232}Th)$) for adult patients. This is due to the fact that the dose coefficient of bone surfaces for ^{232}Th is higher than that of ^{238}U

Table 7. Committed dose equivalents due to ^{238}U (H_T(U) in different tissues and organs of the human body for an adult patient following ingestion of modern phytotherapeutic preparations.

Modern Phytotherapeutic Preparations	H_T(U) (10^{-10} Sv·y^{-1})								E_U (10^{-11} Sv·y^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	Liver (m_T = 1.8 kg)	Kidneys (m_T = 0.31 kg)	Bone surfaces (m_T = 0.12 kg)	Bladder (m_T = 0.045 kg)	
MPP1	78 ± 5	81 ± 5	112 ± 7	192 ± 11	262 ± 16	746 ± 45	1956 ± 117	66 ± 4	85 ± 5
MPP2	84 ± 5	88 ± 5	121 ± 7	208 ± 12	283 ± 17	807 ± 48	2115 ± 127	71 ± 4	92 ± 5
MPP3	85 ± 5	88 ± 5	122 ± 7	210 ± 12	285 ± 17	813 ± 49	2131 ± 128	72 ± 4	93 ± 5
MPP4	49 ± 3	51 ± 3	71 ± 4	123 ± 7	167 ± 10	475 ± 28	1246 ± 75	42 ± 2	54 ± 3
MPP5	88 ± 5	92 ± 5	128 ± 8	219 ± 13	299 ± 18	851 ± 51	2230 ± 134	75 ± 4	97 ± 6
MPP6	87 ± 5	90 ± 5	125 ± 7	215 ± 13	292 ± 17	832 ± 50	2181 ± 131	74 ± 4	95 ± 5.7
MPP7	7.4 ± 0.4	7.7 ± 0.5	10.7 ± 0.6	18 ± 1	25 ± 1.5	72 ± 4	188 ± 11	6.3 ± 0.4	8 ± 0.5
MPP8	11 ± 0.6	11.4 ± 0.7	16 ± 1	27.2 ± 1.6	37 ± 2	105 ± 6	276 ± 17	9.3 ± 0.6	12 ± 0.7
MPP9	87 ± 5	91 ± 6	126 ± 8	217 ± 13	295 ± 18	841 ± 50	2202 ± 132	74 ± 4	96 ± 6
MPP10	118 ± 7	123 ± 7	170 ± 10	293 ± 17	398 ± 24	1134 ± 68	2972 ± 178	100 ± 6	129 ± 8

Table 8. Committed dose equivalents due to ^{238}U (H_T(U) in different tissues and organs of the human body for an adult patient following ingestion of classical phytotherapeutic preparations.

Classical Phytotherapeutic Preparations	H_T(U) (10^{-10} Sv·an^{-1})								E_U (10^{-11} Sv·y^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	Liver (m_T = 1.8 kg)	Kidneys (m_T = 0.31 kg)	Bone surfaces (m_T = 0.12 kg)	Bladder (m_T = 0.045 kg)	
CPP1	87 ± 5	91 ± 5	126 ± 8	217 ± 13	295 ± 18	840 ± 50	2201 ± 132	74 ± 4	96 ± 6
CPP2	95 ± 6	99 ± 6	137 ± 8	236 ± 14	321 ± 19	915 ± 54	2398 ± 144	81 ± 5	104 ± 6
CPP3	92 ± 5	95 ± 6	132 ± 8	228 ± 14	310 ± 19	882 ± 53	2311 ± 139	78 ± 5	101 ± 6
CPP4	50 ± 3	52 ± 3	73 ± 4	125 ± 8	170 ± 10	485 ± 29	1270 ± 76	43 ± 3	55 ± 3
CPP5	105 ± 6	109 ± 6	151 ± 9	260 ± 16	354 ± 22	1007 ± 60	2639 ± 158	89 ± 5	115 ± 7
CPP6	98 ± 6	102 ± 6	142 ± 8	244 ± 15	332 ± 21	945 ± 57	2475 ± 148	84 ± 5	108 ± 6
CPP7	8.7 ± 0.5	9 ± 1	13 ± 1	22 ± 2	29 ± 2	84 ± 5	220 ± 13	7.4 ± 0.4	10 ± 1
CPP8	12 ± 1	13 ± 1	18 ± 1	31 ± 2	42 ± 3	120 ± 7	314 ± 19	11 ± 1	14 ± 1
CPP9	98 ± 6	102 ± 6	142 ± 9	243 ± 15	331 ± 21	943 ± 57	2471 ± 148	84 ± 5	108 ± 6
CPP10	123 ± 7	128 ± 8	177 ± 11	305 ± 18	415 ± 25	1183 ± 71	3099 ± 186	105 ± 6	135 ± 8

Table 9. Committed dose equivalents due to ^{232}Th (H_T(Th) in different tissues and organs of the human body for an adult patient following ingestion of modern phytotherapeutic preparations.

Modern Phytotherapeutic Preparations	H^T(Th) (10^{-10} Sv·y^{-1})											E_{Th} (10^{-10} Sv·y^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	Liver (m_T = 1.8 kg)	Kidneys (m_T = 0.31 kg)	Bone surfaces (m_T = 0.12 kg)	Red marrow (m_T = 1.5 kg)	Testes (m_T = 0.035 kg)	Ovaries (m_T = 0.011 kg)	Bladder (m_T = 0.045 kg	
MPP1	67 ± 4	71 ± 4	88.55 ± 5.31	138 ± 8	318 ± 19	318 ± 19	22,448 ± 1347	778 ± 47	186 ± 11	191 ± 11	66 ± 4	450 ± 27
MPP2	72 ± 4	76 ± 4	94.93 ± 5.69	148 ± 9	341 ± 20	341 ± 20	24,064 ± 1444	834 ± 50	199 ± 12	204 ± 12	70 ± 4	482 ± 29
MPP3	72 ± 4	76 ± 5	95.57 ± 5.73	149 ± 9	343 ± 21	343 ± 21	24,227 ± 1454	840 ± 50	200 ± 12	206 ± 12	71 ± 4	485 ± 29
MPP4	42 ± 2	45 ± 3	55.92 ± 3.35	87 ± 5	201 ± 12	201 ± 12	14,180 ± 851	491 ± 29	117 ± 7	120 ± 7	41 ± 3	284 ± 17
MPP5	76 ± 5	80 ± 5	100.24 ± 6.01	156 ± 9	360 ± 22	360 ± 22	25,410 ± 1525	881 ± 53	210 ± 13	216 ± 13	74 ± 4	509 ± 31
MPP6	74 ± 4	79 ± 5	98 ± 6	153 ± 9	354 ± 21	354 ± 21	24,957 ± 1497	865 ± 52	206 ± 12	212 ± 13	73 ± 4	500 ± 30
MPP7	6.4 ± 0.4	6.7 ± 0.4	8.5 ± 0.5	13 ± 1	31 ± 2	31 ± 2	2157 ± 129	71 ± 4	17 ± 1	17 ± 1	6 ± 0.4	41 ± 2
MPP8	10 ± 1	10 ± 1	12 ± 1	19 ± 1	45 ± 3	45 ± 3	3171 ± 190	110 ± 7	25 ± 2	26 ± 2	8.9 ± 0.6	61 ± 4
MPP9	75 ± 4	79 ± 5	99 ± 6	154 ± 9	356 ± 21	356 ± 21	25,133 ± 1508	871 ± 52	208 ± 12	213 ± 13	73 ± 4	501 ± 30
MPP10	92 ± 5	97 ± 6	122 ± 7	190 ± 11	438 ± 26	438 ± 26	30,933 ± 1856	1072 ± 64	256 ± 15	263 ± 16	90 ± 5	619 ± 37

Table 10. Committed dose equivalents due to ^{232}Th (H_T(Th) in different tissues and organs of the human body for an adult patient following ingestion of classical phytotherapeutic preparations.

Classical Phytotherapeutic Preparations	H_T(Th) (10^{-10} Sv·an^{-1})											E_{Th} (10^{-10} Sv·an^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	Liver (m_T = 1.8 kg)	Kidneys (m_T = 0.31 kg)	Bone surfaces (m_T = 0.12 kg)	Red marrow (m_T = 1.5 kg)	Testes (m_T = 0.035 kg)	Ovaries (m_T = 0.011 kg)	Bladder (m_T = 0.045 kg	
CPP1	75 ± 5	79 ± 5	99 ± 6	154 ± 9	356 ± 21	356 ± 21	25,126 ± 1507	871 ± 52	208 ± 12	213 ± 13	73 ± 4	503 ± 30
CPP2	82 ± 5	87 ± 5	108 ± 7	169 ± 10	389 ± 23	389 ± 23	27,472 ± 1648	952 ± 57	227 ± 14	233 ± 14	80 ± 5	550 ± 33
CPP3	79 ± 5	84 ± 5	105 ± 6	163 ± 10	376 ± 23	376 ± 23	26,512 ± 1591	919 ± 55	219 ± 13	225 ± 14	77 ± 5	531 ± 32
CPP4	43 ± 3	46 ± 3	57 ± 3	89 ± 5	206 ± 12	206 ± 12	14,519 ± 871	503 ± 30	120.02 ± 7.2	123 ± 7	42 ± 2	291 ± 17
CPP5	90 ± 5	95 ± 6	119 ± 7	185 ± 11	428 ± 26	428 ± 26	30,196 ± 1812	1047 ± 63	250 ± 15	257 ± 15	88 ± 5	604 ± 36
CPP6	85 ± 5	89 ± 5	112 ± 7	174 ± 10	402 ± 24	402 ± 24	28,354 ± 1701	983 ± 59	234 ± 14	241 ± 14	83 ± 5	568 ± 34
CPP7	7.5 ± 0.5	7.9 ± 0.5	10 ± 1	15 ± 1	36 ± 2	36 ± 2	2516 ± 151	87 ± 5	21 ± 1	21.38 ± 1.28	7.3 ± 0.4	50 ± 3
CPP8	11 ± 1	11 ± 1	14 ± 1	22 ± 1	51 ± 3	51 ± 3	3585 ± 215	124 ± 7	30 ± 2	30 ± 2	10 ± 1	72 ± 4
CPP9	84 ± 5	89 ± 5	111 ± 7	173 ± 10	400 ± 24	400 ± 24	28,201 ± 1692	977 ± 9	233 ± 14	240 ± 14	82 ± 5	564 ± 34
CPP10	105 ± 6	111 ± 7	139 ± 8	217 ± 13	501 ± 30	501 ± 30	35,338 ± 212	1225 ± 73	292 ± 18	300 ± 18	103 ± 6	707 ± 42

Table 11. Committed dose equivalents due to ^{222}Rn ($H_T(^{222}Rn)$) in different tissues and organs of the human body for an adult patient following ingestion of classical phytotherapeutic preparations.

Classical Phytotherapeutic Preparations	$H_T(^{222}Rn)$ (10^{-8} Sv·y^{-1})				$E(^{222}Rn)$ (10^{-8} Sv·y^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	
CPP1	29 ± 2	31 ± 2	139 ± 8	136 ± 8	22 ± 1
CPP2	32 ± 2	34 ± 2	152 ± 9	148 ± 9	24 ± 2
CPP3	31 ± 2	32 ± 2	146 ± 9	143 ± 9	23 ± 1
CPP4	17 ± 1	18 ± 1	80 ± 5	78 ± 5	12 ± 1
CPP5	35 ± 2	37 ± 2	167 ± 10	163 ± 10	26 ± 2
CPP6	33 ± 2	35 ± 2	157 ± 9	153 ± 9	24 ± 2
CPP7	2.9 ± 0.2	3.1 ± 0.2	14 ± 1	13 ± 1	2.1 ± 0.1
CPP8	4.2 ± 0.3	4.4 ± 0.3	20 ± 1	19 ± 1	3.1 ± 0.2
CPP9	33 ± 2	35 ± 2	156 ± 9	152 ± 9	24 ± 2
CPP10	41 ± 3	44 ± 3	196 ± 12	191 ± 11	30 ± 2

Table 12. Committed dose equivalents due to ^{222}Rn ($H_T(^{222}Rn)$) in different tissues and organs of the human body for an adult patient following ingestion of modern phytotherapeutic preparations.

Modern Phytotherapeutic Preparations	$H_T(^{222}Rn)$ (10^{-8} Sv·y^{-1})				$E(^{222}Rn)$ (10^{-8} Sv·y^{-1})
	Stomach (m_T = 0.15 kg)	Small intestine (m_T = 0.64 kg)	Upper large Intestine (m_T = 0.21 kg)	Lower large Intestine (m_T = 0.16 kg)	
MPP1	26 ± 2	27 ± 2	124 ± 7	121 ± 7	19 ± 1
MPP2	28 ± 2	30 ± 2	134 ± 8	131 ± 8	21 ± 1
MPP3	28 ± 2	30 ± 2	135 ± 8	131 ± 8	21 ± 1
MPP4	16 ± 1	18 ± 1	79 ± 5	77 ± 5	12 ± 1
MPP5	29 ± 2	31 ± 2	141 ± 8	138 ± 8	22 ± 1
MPP6	29 ± 2	31 ± 2	138 ± 8	135 ± 8	21 ± 1
MPP7	2.4 ± 0.2	2.6 ± 0.1	12 ± 1	12 ± 1	1.8 ± 0.1
MPP8	3.6 ± 0.2	4 ± 0.2	17 ± 1	17 ± 1	2.7 ± 0.2
MPP9	29 ± 2	31 ± 2	139 ± 8	136 ± 8	22 ± 2
MPP10	39 ± 2	42 ± 2	188 ± 11	183 ± 11	29 ± 2

For all preparations, the committed equivalent doses due to radon are high in the lower large intestine and in the upper large intestine than in the other organs of the gastrointestinal system. This is due to the fact that these organs show a higher cumulative activity than the others.

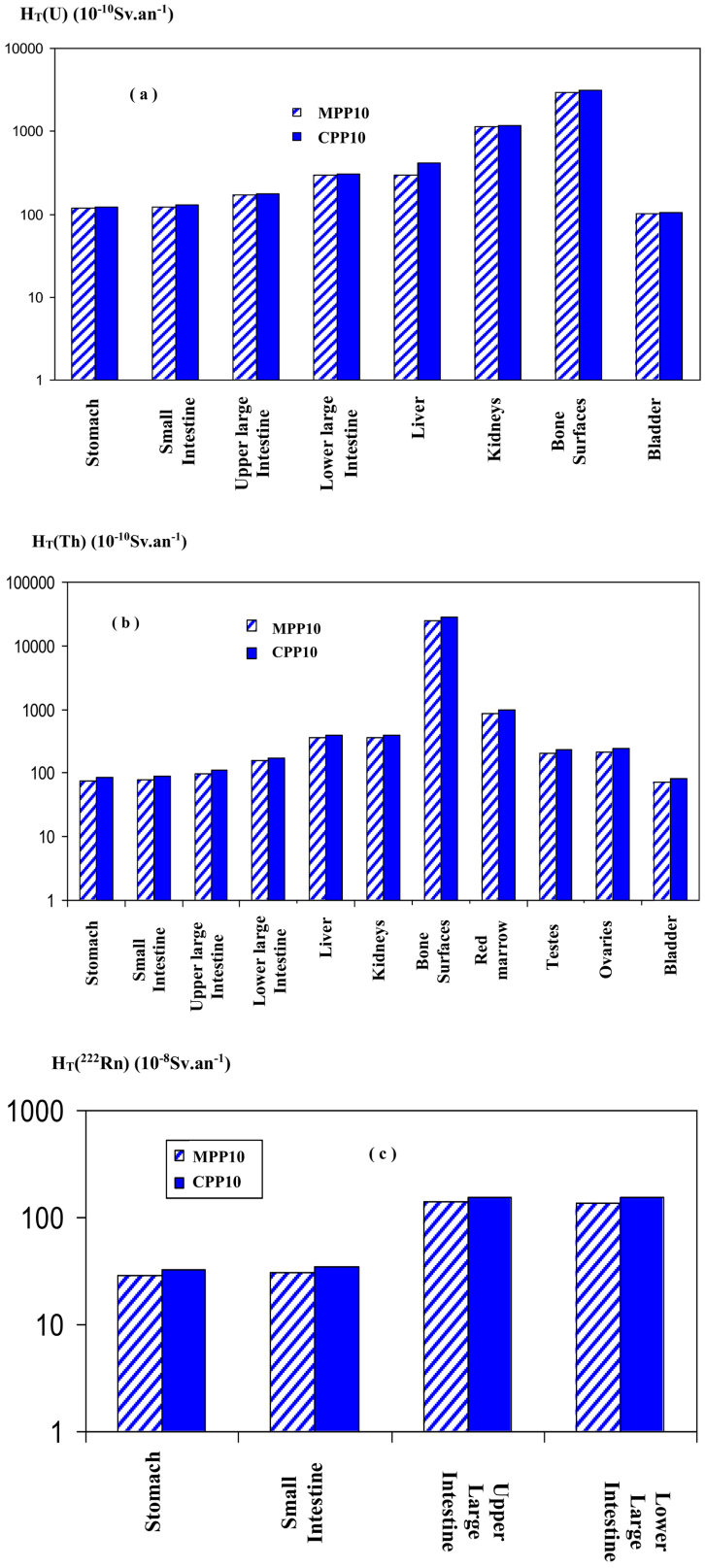

Figure 2. Comparison of annual committed dose equivalents due to ^{238}U (a); ^{232}Th (b) and ^{222}Rn (c) in different human tissues and organs following ingestion of phytotherapeutic preparations: MPP10 and CPP10.

Even if the large upper intestine and stomach have practically similar masses, the equivalent dose is clearly high in the first organ than in the last organ. This difference is due to the fact that the large upper intestine has an average residence time, higher than that of the stomach

We note that the stomach and small intestine show almost identical committed dose equivalents even if they have different masses and integrals of alpha activities: there is compensation between the effects of the mass and the integral alpha activity.

The committed equivalent doses in all organs due to ^{238}U, ^{232}Th and ^{222}Rn in the case of classical phytotherapeutic preparations are higher than in the case of modern phytotherapeutic preparations. This cannot be explained only by the effect of pollution which exists in the case of classical preparations.

The overall committed annual effective doses due to ^{238}U, ^{232}Th and ^{222}Rn following ingestion of various phytotherapeutic preparations were evaluated in the human body of Moroccan adult patients. The results are shown in Table 13.

The maximum value for the overall annual committed effective dose due to ^{238}U, ^{232}Th and ^{222}Rn following ingestion of the preparations studied was found to be equal to $(38 \pm 3) \times 10^{-8}$ Sv·year^{-1}) for patients who consume the preparation CPP10. This value is smaller than the global mean value for ingestion (between 0.2 and 0.8 mSv·y^{-1}). But there will be a risk if the amount taken by the patient is large, especially since generally patients who use phytotherapy do not respect the doses prescribed by phytotherapists, in comparison with the case of doctors.

The dose ingestion coefficients per unit of intake following the ingestion of ^{238}U ($h_T(^{238}\text{U})$) and ^{232}Th ($h_T(^{232}\text{Th})$) for different tissues and organs of the human body were determined by using our method. The results obtained are in good agreement with those given by the International Commission on Radiological Protection (ICRP) [17] (Table 14).

Table 13. Values of the overall effective dose due to uranium; thorium and radon after ingestion of various phytotherapeutic preparations.

Modern Phytotherapeutic Preparations	$E_{U+Th+^{222}Rn}$ (10^{-8} Sv·y^{-1})	Classical Phytotherapeutic Preparations	$E_{U+Th+^{222}Rn}$ (10^{-8} Sv·y^{-1})
MPP1	24 ± 2	**CPP1**	27 ± 2
MPP2	26 ± 2	**CPP2**	29 ± 2
MPP3	26 ± 2	**CPP3**	28 ± 2
MPP4	15 ± 1	**CPP4**	15 ± 1
MPP5	27 ± 2	**CPP5**	32 ± 2
MPP6	26 ± 2	**CPP6**	30 ± 2
MPP7	2.3 ± 0.2	**CPP7**	2.7 ± 0.2
MPP8	3.33 ± 0.25	**CPP8**	3.8 ± 0.3
MPP9	27 ± 2	**CPP9**	30 ± 2
MPP10	35 ± 3	**CPP10**	38 ± 3

Table 14. Values of the dose ingestion coefficients of ^{238}U ($h_T(U)$) and ^{232}Th ($h_T(Th)$) for different tissues and organs of the human body.

Tissue/organ	Dose coefficient h_T (10^{-8} Sv·Bq^{-1})			
	Our method		ICRP	
	^{238}U	^{232}Th	^{238}U	^{232}Th
Stomach	2.7 ± 0.2	3.8 ± 0.3	2.6	3.7
Small intestine	2.8 ± 0.2	4 ± 0.3	2.7	3.8
Upper large Intestine	3.9 ± 0.3	5 ± 0.3	3.9	5.1
Lower large Intestine	6.8 ± 0.4	7.8 ± 0.5	6.9	8.0
Liver	8.9 ± 0.6	18 ± 1	9.6	18
Kidneys	26 ± 2	18 ± 2	25	18
Bone surfaces	68 ± 4	1274 ± 92	71	1200
Red marrow	----	44 ± 4	----	46
Testes	----	10 ± 1	----	10
Ovaries	----	11 ± 1	----	10
Bladder	2.3 ± 0.2	3.7 ± 0.2	2.25	3.6

3. Conclusions

In this study, we measured the concentrations of uranium-238, thorium-232, radon-222 and thoron-220 present in various examples of various phytotherapeutic preparations, by the use of a method based on the determination of the detection efficiencies of LR-115 II and CR-39 SSNTDs.

We found that all of phytotherapeutic preparations studied contain more thorium than uranium.

We noted that the concentrations of uranium, thorium and radon measured in classical phytotherapeutic preparations are higher than those of modern phytotherapeutic preparations.

We also determined the alpha activities due to the incorporation of ^{238}U, ^{232}Th and ^{222}Rn following ingestion of phytotherapeutic preparations studied in different compartments of the human body of adult patients using dosimetric models of the International Commission on Radiological Protection. These intakes depend on the type of sample and the nature of the disease.

We evaluated the overall committed annual effective doses due to ^{238}U, ^{232}Th and ^{222}Rn in the human body of Moroccan adult patients following ingestion of various phytotherapeutic preparations.

We calculated using our method, the committed dose coefficients per unit of intake per ingestion of ^{238}U ($h_T(^{238}U)$) and ^{232}Th ($h_T(^{232}Th)$) for different tissues and organs of the human body that we compared to those given by the International Commission on Radiological Protection (ICRP) [13].

The method used is precise, because the relative uncertainty on the various measurements performed does not exceed 10%, it does not require prior calibra-

tion, and it is non-destructive, sensitive and less expensive.

It is noted that these preparations do not present a radiological danger for the health of patients, because the maximum value calculated for the overall annual effective dose committed due to ^{238}U, ^{232}Th and ^{222}Rn following this ingestion was found to be very small (0.38 $\mu Sv \cdot y^{-1}$) relative to the global mean value for ingestion (between 0.2 and 0.8 $mSv \cdot y^{-1}$). But that overdose poses a real risk of increased radiation doses to adult patients following ingestion of phytotherapeutic preparations.

The analyses carried out helped to fill the gap that existed concerning the radioactivity data of phytotherapeutic drugs.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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