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^{238}U and ^{232}Th Contents in Essential Plant Oils: Alpha and Beta Radiation Doses to the Skin of Bathers in Spa Rooms

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Abstract

Essential plant oils are widely used by bathers in spa rooms for body firming, anti-aging, and anti-wrinkle and skin firming. To explore the exposure pathway of ^{238}U, ^{232}Th and their progenies to the skin of bathers in spa rooms, these radionuclides were measured in various essential oils extracted from different plants by using CR-39 and LR-115 II solid state nuclear track detectors (SSNTDs). Annual equivalent doses to skin due to alpha- and beta-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series from the application of different plant oil samples by adult male bathers in spa rooms were evaluated. The influence of the essential plant oil nature and exposure time of bathers in spa rooms was investigated. The maximum total equivalent dose to the skin of bathers in spa rooms, due to the application of L'olivier plant oil during 4 hours per week, was found equal to 0.6 mSv y^{-1} cm^{-2}.

Keywords: Essential plant oils; nuclear track detectors; alpha and beta dose assessment to skin; spa

1. INTRODUCTION

Natural radionuclides existed since the creation of the planet earth some 4.5 billion years ago. Those which have half-lives smaller than the earth's age have decayed into stable nuclei. However, some primordial radionuclides whose half-lives are as long as the earth's age still present. Among these long half-live radionuclides some belong to the three natural radioactive series defined by their longest parent: ^{238}U which has a half-life of 4.5 10^9 y, ^{232}Th which has a half-life of 14.0 10^9 y, and ^{235}U which has a half-life of 0.7 10^9 y, respectively. These radioactive series terminate in ^{206}Pb, ^{208}Pb, and ^{207}Pb stable nuclei, respectively. The radionuclides of the ^{238}U, ^{232}Th, and ^{235}U series emit alpha and beta-particles as well as gamma rays. It has been shown that alpha radiation doses are deposited in skin of individuals following the immersion in thermal water [1], and application of olive oil [2], medical drugs [3] and petrol [4]. It also has been shown that alpha doses are deposited in the eye tissues of individuals from the plate out of radon and thoron progeny present in ambient air in dwellings and workplaces [5]. Naturally occurring radionuclides are transferred from the soil to plants via water and then to essential oils which are utilized by bathers in spa rooms.

^{238}U and ^{232}Th contents have been measured in different vegetation samples in India by using gamma spectrometry using hyper pure germanium detector (HPGe) [6]. By using the male and female reference computational phantoms [7] and different Monte Carlo codes, radiation doses to human skin due to external exposure to alpha and beta-particles have been calculated [8]. But this model does not take into account the specificity of each individual. Our main motivation to conduct this study consists in developing new dosimetric models to assess alpha and beta radiation doses to the skin of bathers by taking into account the concentrations of ^{238}U, and ^{232}Th in different essential plant oil samples and skin surface of each individual.

In the present work, we used CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) to evaluate ^{238}U and ^{232}Th concentrations inside various essential oils extracted from different plants. We evaluated equivalent doses to skin due to alpha- and beta-particles emitted by the ^{238}U and ^{232}Th series from the application of different essential oils by adult bathers inside spa rooms.

2. MATERIALS AND METHODS

a. Description of the essential plant oil samples and spa rooms studied

Different essential plant oil samples, extracted from various medicinal and aromatic plants, widely used by bathers in four spa rooms in the city of Marrakech (Morocco) have been collected and analyzed as shown in Table 4. The volume of the studied spa rooms varies between 26.25 m^3 and 40.50 m^3.

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Temperature and pressure inside the studied spa rooms are respectively equal to 40 C° and 968.7 hPa.

b. Determination of ^{238}U and ^{232}Th concentrations in different plant oil samples

Different essential plant oil samples were placed in direct contact with CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) in cylindrical plastic caps properly closed for 30 days as shown in Fig.1 [9].

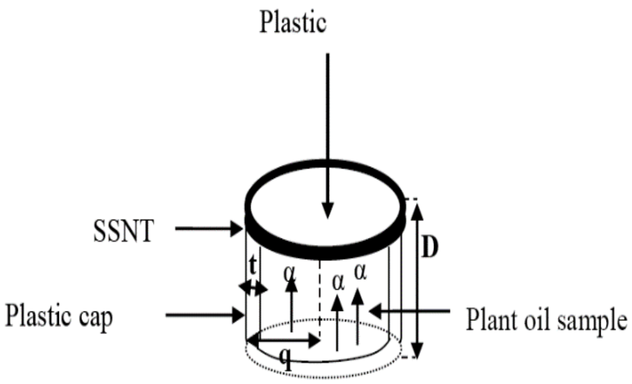

Fig. 1. Arrangement of a plant oil material sample on a solid state nuclear track detector (SSNTD) in a well-sealed plastic cap of radius q=2cm, depth D=1cm and thickness t=5mm. Glue is put between the plastic cover and plastic container and both are covered by a cellophane tape of 2 mm thickness. α represent alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series inside a plant oil sample.

During the exposure time, alpha-particles emitted by ^{238}U, ^{232}Th and their progenies bombarded the SSNTD films. After this exposure, the CR-39 and LR-115 II films were etched in two NaOH solutions at optimal conditions ensuring good reproducibility of the method and good sensitivity of detectors utilised as described in Ref. [9]. Since the detection system utilized was hermitically sealed (there was no escape of radon and thoron), there was no addition of chemical agent to the essential plant oil sample, and the exposure time was 30 d, a radioactive secular equilibrium was established between ^{238}U and each of its progeny and between ^{232}Th and each of its progeny. Global net track density rates (tracks cm^{-2} s^{-1}) due to alpha-particles emitted by the series of ^{238}U and ^{232}Th recorded on the CR-39 detectors (ρ_G^{CR}) and LR-115 II films (ρ_G^{LR}), after subtracting the corresponding backgrounds, are given by the following expressions [9]:

$$\frac{A_c\left(^{232}Th\right)}{A_c\left(^{238}U\right)} = \frac{\frac{S_d^{'}}{S_d}\sum_{j=1}^{8} k_{\alpha j}\varepsilon_{\alpha j}^{CR} R_{\alpha j} - \frac{\rho_G^{CR}}{\rho_G^{LR}}\sum_{j=1}^{8} k_{\alpha j}\varepsilon_{\alpha j}^{LR} R_{\alpha j}}{\frac{\rho_G^{CR}}{\rho_G^{LR}}\sum_{j=1}^{7} k_{\alpha j}^{'}\varepsilon_{\alpha j}^{'CR} R_{\alpha j}^{'} - \frac{S_d^{'}}{S_d}\sum_{j=1}^{7} k_{\alpha j}^{'}\varepsilon_{\alpha j}^{'LR} R_{\alpha j}^{'}} \qquad (1)$$

and

$$A_c\left(^{238}U\right) = \frac{2 S_d \, \rho_G^{CR}}{\pi q^2\left[\sum_{j=1}^{8} k_{\alpha j}\varepsilon_{\alpha j}^{LR} R_{\alpha j} + \frac{A_c\left(^{232}Th\right)}{A_c\left(^{238}U\right)}\sum_{j=1}^{7} k_{\alpha j}^{'}\varepsilon_{\alpha j}^{'LR} R_{\alpha j}^{'}\right]} \qquad (2)$$

where $A_c\left(^{238}U\right)$ (in Bq cm^{-3}) is the activity per unit volume of ^{238}U inside a plant oil sample, $A_c\left(^{232}Th\right)$ (in Bq cm^{-3}) is the activity per unit volume of ^{232}Th inside a plant oil sample, q (cm) is the radius of the plastic cap, S_d (cm^2) and $S_d^{'}$ (cm^2) are respectively the surface areas of the CR-39 and LR-115 II films, $R_{\alpha j}$ (cm) and $R_{\alpha j}^{'}$ (cm) are the ranges, in the plant oil sample, of an alpha-particle of index j and initial energy $E_{\alpha j}$ emitted by the nuclei of the uranium and an alpha-particle of index j' and initial energy $E_{\alpha j'}$ emitted by the nuclei of thorium series (Table 1), respectively, $k_{\alpha j}$ and $k'_{\alpha j}$ are respectively the branching ratios corresponding to the alpha disintegration of the nuclei of the uranium and thorium series (Table 1) and $\varepsilon_{\alpha j}^{CR}$, $\varepsilon_{\alpha j}^{'CR}$, $\varepsilon_{\alpha j}^{LR}$ and $\varepsilon_{\alpha j}^{'LR}$ are respectively the detection efficiencies of the CR-39 and LR-115 II detectors for the emitted alpha-particles [9] (Table 1).

By calculating detection efficiencies of track detectors CR-39 ($\varepsilon_{\alpha j}^{CR}$, $\varepsilon_{\alpha j}^{'CR}$) and LR-115 type II ($\varepsilon_{\alpha j}^{LR}$, $\varepsilon_{\alpha j}^{'LR}$) using the code "SSNTDEαM" [9] (Table 1) and counting track density rates recorded on films (ρ_G^{CR}, ρ_G^{LR}), the ratio and then the activities due to uranium ($A_c\left(^{238}U\right)$ expressed in Bq cm^{-3}) and thorium ($A_c\left(^{232}Th\right)$ expressed in Bq cm^{-3}) contained in plant oil samples were determined.

The ranges of the emitted alpha-particles in plant oil samples and SSNTDs were calculated by using the SRIM programme [10].

c. Evaluation of annual equivalent doses to skin due to alpha-particles emitted by the ^{238}U and ^{232}Th series from the application of essential plant oil samples

The human skin is formed by a series of three layers: The epidermis which has a 50-100 μm depth, the dermis which has a depth of some mm, and the hypodermis with a depth of some mm to 1 cm. The epidermis of the human skin is divided into several clearly defined zones [11]. Indeed, when a plant oil material layer is deposited on the skin of a bather (Fig. 2), the emitted alpha-particles have ranges of several tens of microns (20 to 100µm). This is comparable with the depth of the basal layer of the epidermis which is more sensitive (50 to 100µm) [8].

Table 1. Data obtained for ranges of alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series ($R_{\alpha j}$ and $R_{\alpha j'}$) in plant oil. $E_{\alpha j}$ and $E_{\alpha j'}$ are respectively the initial energies of alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series inside a plant oil sample. $k_{\alpha j}$ and $k'_{\alpha j}$ are respectively the branching ratios corresponding to the alpha disintegration of the nuclei of the ^{238}U and ^{232}Th series. $\varepsilon_{\alpha j}^{CR}$, $\varepsilon_{\alpha j}^{'CR}$, $\varepsilon_{\alpha j}^{LR}$ and $\varepsilon_{\alpha j}^{'LR}$ are respectively the detection efficiencies of the CR-39 and LR-115 II detectors for the emitted alpha-particles.

Radionuclide	$E_{\alpha j}$ (MeV)	$k_{\alpha j}$	$R_{\alpha j}$ (µm)	$\varepsilon_{\alpha j}^{LR}$ (%)	$\varepsilon_{\alpha j}^{CR}$ (%)
(a) Uranium family					
^{238}U	4.19	1	28.04	33.80	63.52
^{230}Th	4.62	1	33.21	36.55	66.85
^{234}U	4.77	1	34.72	35.83	68.28
^{226}Ra	4.78	1	34.82	35.51	67.97
^{210}Po	5.30	1	40.31	31.21	71.59
^{222}Rn	5.49	1	42.42	29.13	72.92
^{218}Po	6.00	1	48.31	25.86	75.30
^{214}Po	7.68	1	70.43	17.81	82.21

Radionuclide	$E_{\alpha j'}$ (MeV)	$k'_{\alpha j}$	$R_{\alpha j'}$ (µm)	$\varepsilon_{\alpha j'}^{LR}$ (%)	$\varepsilon_{\alpha j'}^{CR}$ (%)
(b) Thorium family					
^{232}Th	4.01	1	27.37	32.93	61.89
^{228}Th	5.42	1	41.64	30.19	72.21
^{224}Ra	5.71	1	44.91	27.65	74.07
^{212}Bi	6.05	0.36	48.79	25.42	75.69
^{220}Rn	6.29	1	51.71	24.27	77.04
^{216}Po	6.78	1	58.24	21.22	79.03
^{212}Po	8.78	0.64	87.24	14.48	84.96

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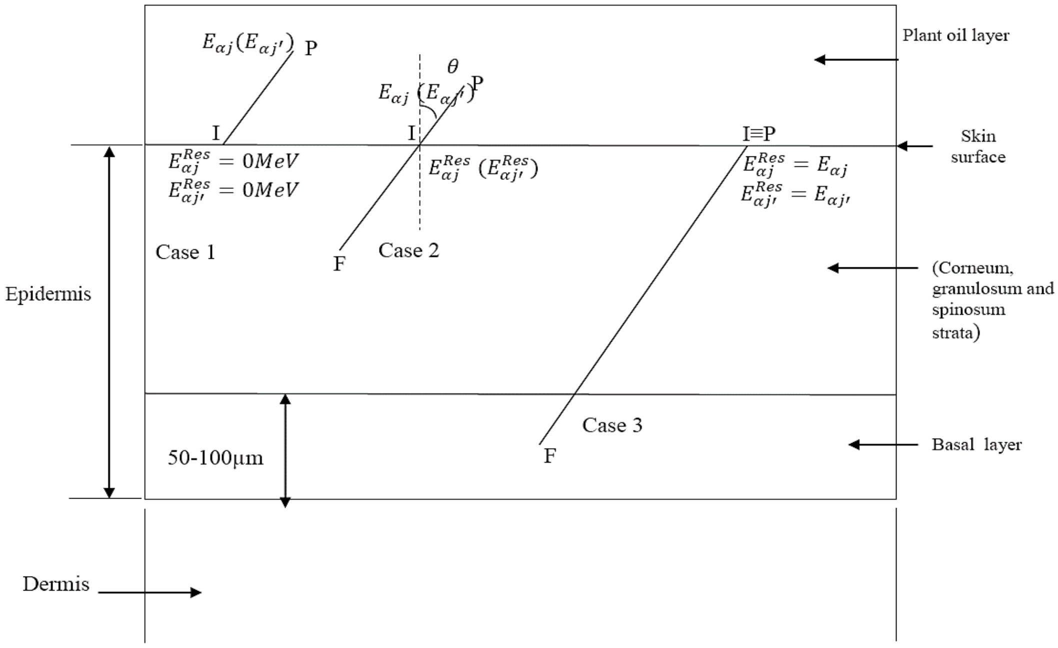

Fig. 2(a). Ranges of an alpha-particle emitted by a nucleus belonging to the ^{238}U series inside a plant oil material layer ($\overline{PI} = x_j$) and epidermis ($\overline{IF} = R_j^{skin}$): $E_{\alpha j}$ is the initial alpha-particle energy and $E_{\alpha j}^{Res}$ its residual energy on the point I. Ranges of an alpha-particle emitted by a nucleus belonging to the ^{232}Th series inside a plant oil material layer ($\overline{PI} = x_{j'}$) and epidermis ($\overline{IF} = R_{j'}^{skin}$): $E_{\alpha j'}$ is the initial alpha-particle energy and $E_{\alpha j'}^{Res}$ its residual energy on the point I. The plant oil material layer has a depth of about 1 mm.

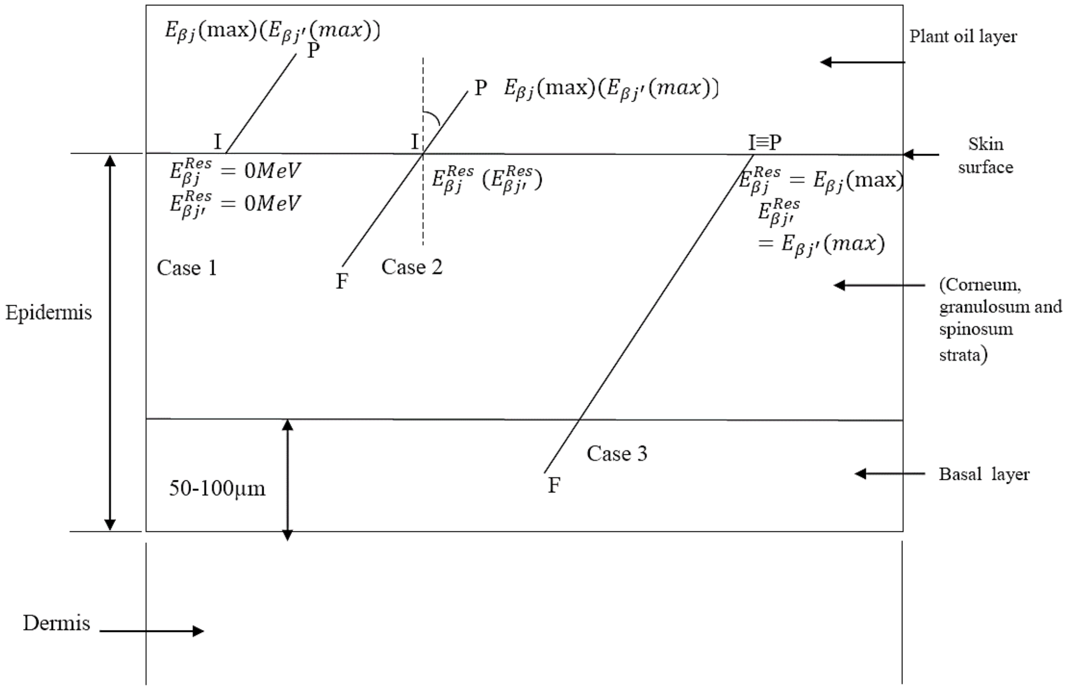

Fig. 2(b). Ranges of a beta-particle emitted by a nucleus belonging to the ^{238}U series inside a plant oil material layer ($\overline{PI} = x_j$) and epidermis ($\overline{IF} = R_j^{skin}$): $E_{\beta j}(\max)$ is the initial beta-particle energy and $E_{\beta j}^{Res}$ its residual energy on the point I. Ranges of a beta-particle emitted by a nucleus belonging to the ^{232}Th series inside a plant oil material layer ($\overline{PI} = x_{j'}$) and epidermis ($\overline{IF} = R_{j'}^{skin}$): $E_{\beta j'}(\max)$ is the initial beta-particle energy and $E_{\beta j'}^{Res}$ its residual energy on the point I. The plant oil material layer has a depth of about 1 mm.

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Table 2. Data obtained for ranges ($R_{\alpha j}$ and $R_{\alpha j'}$), in skin, of alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series. T is the half-life of a radionuclide belonging to the ^{238}U and ^{232}Th series.

Radionuclide	T	$E_{\alpha j}$ (MeV)	k_j	$R_{\alpha j}$ (μm)
(a) Uranium series				
^{238}U	4.5×10^{9} y	4.19	1	25.64
^{230}Th	8×10^{4} y	4.62	1	29.52
^{234}U	2.446×10^{5} y	4.77	1	30.93
^{226}Ra	1620 y	4.78	1	31.03
^{210}Po	138.3 d	5.30	1	36.16
^{222}Rn	3.82 d	5.49	1	38.13
^{218}Po	3.05 min	6.00	1	43.64
^{214}Po	1.6×10^{-4} s	7.68	1	64.19
Radionuclide	T	$E_{\alpha j'}$ (MeV)	k'_j	$R_{\alpha j'}$ (μm)
(b) Thorium series				
^{232}Th	1.4×10^{10} y	4.01	1	24.09
^{228}Th	1.90 y	5.42	1	37.39
^{224}Ra	6.3 d	5.71	1	40.46
^{212}Bi	60.5 min	6.05	0.36	44.19
^{220}Rn	55 s	6.29	1	46.93
^{216}Po	0.158 s	6.78	1	52.73
^{212}Po	3.7×10^{-7} s	8.78	0.64	79.62

The ranges of alpha-particles emitted by the ^{238}U and ^{232}Th series in skin were calculated by using the SRIM code[10] and composition data for skin [11] (Table 2).

An alpha-particle of index j and initial energy E_{α_j} emitted from a nucleus , belonging to the ^{238}U series, localized at the point P inside a plant oil material layer (Fig. 2a) has a range, $\overline{PF}$,

$$\overline{PF} = x_j + R_{\alpha_j}^{skin} \quad (3)$$

where x_j ($x_j \le R_{\alpha_j}$ and R_{α_j} is the range of the alpha-particle in plant oil) is the distance between the point of emission and the skin (Fig. 2(a)) and $R_{\alpha_j}^{skin}$ is the range of the alpha- particle in skin.

The alpha-particle residual energy $E_{\alpha_j}^{Res}$, which corresponds to the (R_{α_j} - x_j) range, is determined by using the energy-range relationship in plant oil obtained by fitting the curve represented in Fig. 3(a). By using the energy–range relationship in skin (obtained by fitting the curve represented in Fig. 3(b)) one can determine the range of the alpha-particle in skin $R_{\alpha_j}^{Skin}$.

For $x_j = R_{\alpha_j}$, $E_{\alpha_j}^{Res} = 0\ MeV$; there is no energy loss of alpha-particles in skin (case 1 of Fig. 2(a)).

For an alpha-particle emitted at the surface of skin $x_j = 0\ \mu m$, $E_{\alpha_j}^{Res} = E_{\alpha_j}$; the energy loss of alpha particles in skin is maximum ($R_{\alpha_j}^{Skin}$ maximum) (case 3 of Fig. 2(a)). For $x_j < R_{\alpha j}$, $E_{\alpha_j}^{Res} < E_{\alpha_j}$; the ranges of alpha-particles in skin are lower than those corresponding to $x_j = 0\ \mu m$ (case 2 of Fig. 2(a)).

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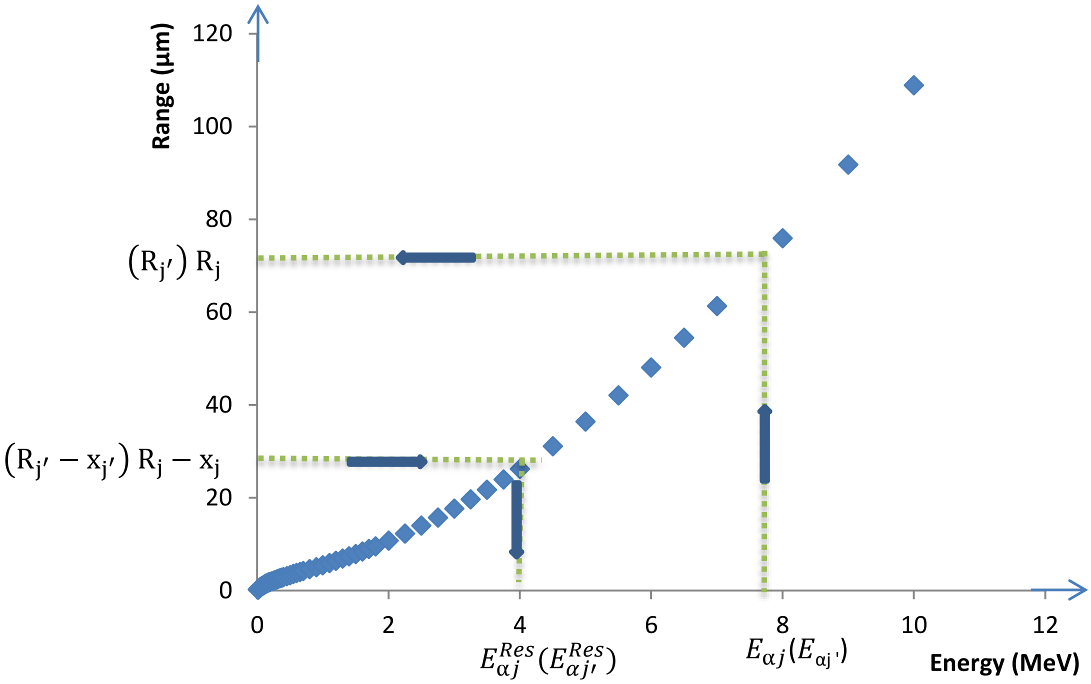

Fig. 3(a)

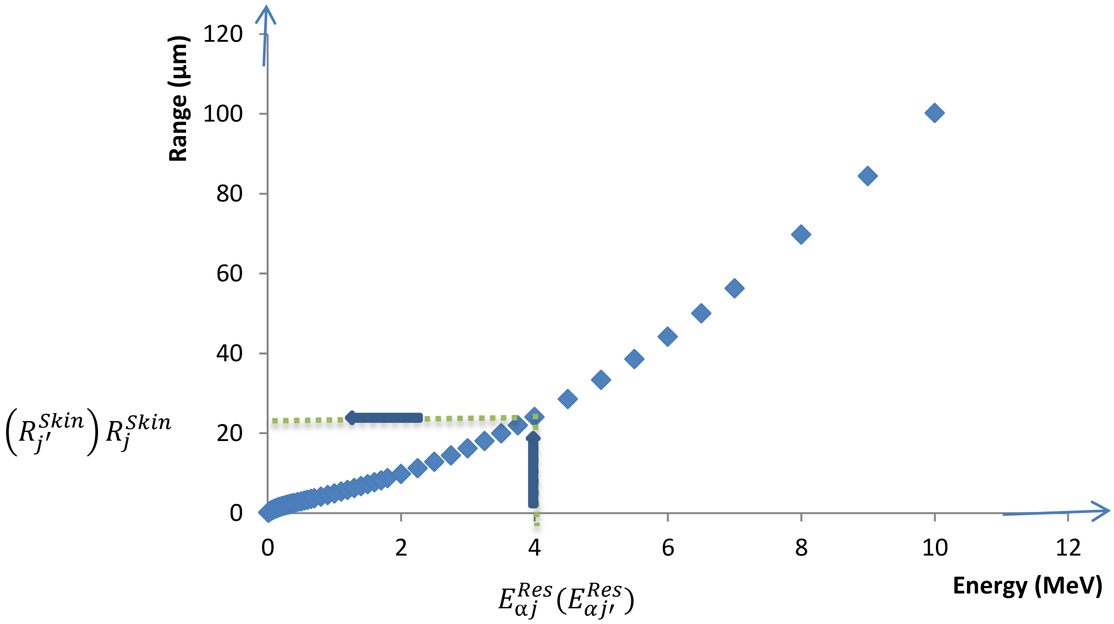

Fig. 3(b)

Fig. 3. Variation of alpha-particle range as a function of alpha-particle energy in plant oil (a) and skin (b).

Similarly an alpha-particle of index j' and initial energy $E_{\alpha_j'}$ emitted from a nucleus, belonging to the ^{232}Th series, localized at the point P inside a plant oil material layer (Fig. 2(a)) has a range, $\overline{PF}$,

$$\overline{PF} = x_{j'} + R^{skin}_{\alpha j'} \quad (4)$$

Where $x_{j'}$, ($x_{j'} \le R_{\alpha_j'}$ and $R_{\alpha_j'}$ is the range of the alpha-particle in plant oil) is the distance between the point of emission and the skin (Fig. 2(a)) and $R_{\alpha_{j'}}^{skin}$ is the range of the alpha particle in skin.

The alpha-particle residual energy $E_{\alpha_{j'}}^{\mathrm{Res}}$, which corresponds to the ($R_{\alpha_{j'}}$-$x_{j'}$) range, is determined by using the energy-range relationship in plant oil obtained by fitting the curve represented in Fig. 3(a). By using the energy–range relationship in skin (obtained by fitting the curve represented in Fig. 3(b)) one can determine the range of the alpha particle in skin $R_{\alpha_{j'}}^{Skin}$.

For $x_{j'} = R_{\alpha_{j'}}$, $E_{\alpha_{j'}}^{\mathrm{Res}} = 0\ MeV$; there is no energy loss of alpha-particles in skin (case 1 of Fig. 2(a)).

For an alpha particle emitted at the surface of skin $x_{j'} = 0\ \mu m$, $E_{\alpha_{j'}}^{\mathrm{Res}} = E_{\alpha_{j'}}$; the energy loss of alpha particles in skin is maximum ($R_{\alpha_{j'}}^{Skin}$ maximum) (case 3 of Fig. 2(a)). For $x_{j'} < R_{\alpha j'}$, $E_{\alpha_{j'}}^{\mathrm{Res}} < E_{\alpha_{j'}}$; the ranges of alpha-particles in skin are lower than those corresponding to $x_{j'} = 0\ \mu m$ (case 2 of Fig. 2(a)).

Annual equivalent doses to skin (Sv) due to all residual energies of an alpha-particle of index j and initial energy $E_{\alpha j}$ belonging to the ^{238}U series and an alpha-particle of index j' and initial energy $E_{\alpha j'}$ belonging to the ^{232}Th series are respectively given by [12]:

$$H(j) = \frac{k K_j A_C^{clay}(^{238}U)(1-e^{-\lambda_j t_e})}{2\lambda_j \rho_{skin} S_{skin} \Delta E_{\alpha j}^{Res}} \int_0^{E_{\alpha j}} \frac{E_{\alpha j}^{Res}}{R_{\alpha j}^{skin}(E_{\alpha j}^{Res})} dE_{\alpha j}^{Res} \quad (18) \text{and}$$

$$H(j') = \frac{k\, k'_{\alpha j}\ A_c^{plantoil}(^{232}Th)(1-e^{-\lambda_{j'} t_e}) W_R}{2\lambda_{j'} \rho_{skin} S_{skin} \Delta E_{\alpha j'}^{Res}} \int_0^{E_{\alpha j'}} \frac{E_{\alpha j'}^{Res}}{R_{\alpha j'}^{skin}(E_{\alpha j'}^{Res})} dE_{\alpha j'}^{Res} \quad (6)$$

Where $k_{\alpha j}$ and $k'_{\alpha j}$ are respectively the branching ratios corresponding to the alpha disintegration of the nuclei of the ^{238}U and ^{232}Th series; W_R is the radiation weighting factor which is equal to 20 for alpha-particles [11]; $A_C^{plantoil}(^{238}U)$ (Bq cm^{-3}) is the activity due to ^{238}U in a plant oil sample; $A_C^{plantoil}(^{232}Th)$ (Bq cm^{-3}) is the activity due to ^{232}Th in a plant oil sample; λ_j is the radioactive decay constant of a radionuclide of index j belonging to the ^{238}U series; $\lambda_{j'}$ is the radioactive decay constant of a radionuclide of index j' belonging to the ^{232}Th series; ρ_{skin} is the density of skin (g cm^{-3}); S_{skin} is the skin surface (cm^2); k = 1.6.10^{-13} (J MeV^{-1}) is a conversion factor; $R_{\alpha_j}^{skin}$ is the range, in skin, of an alpha-particle of index j and residual energy $E_{\alpha_j}^{\mathrm{Res}}$ belonging to the ^{238}U series and $R_{\alpha_{j'}}^{skin}$ is the range, in skin, of an alpha-particle of index j' and residual energy $E_{\alpha_{j'}}^{\mathrm{Res}}$ belonging to the ^{232}Th series (Fig. 2(a)); t_e is the exposure time; and $\Delta E_{\alpha_j}^{\mathrm{Res}}$ and $\Delta E_{\alpha_{j'}}^{\mathrm{Res}}$ are respectively the chosen steps on the [0-$E_{\alpha j}$] and [0-$E_{\alpha j'}$] energy intervals (Table 3).

Table 3. Data obtained for ranges (R_{β_j} and $R_{\beta_{j'}}$) in skin of beta-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series. $E_{\beta j}$ (max) and $E_{\beta j'}$ (max) are respectively the initial energies of beta-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series inside a plant oil sample. $k_{\beta j}$ and $k_{\beta j'}$ are respectively the branching ratios corresponding to the beta disintegration of the nuclei of the ^{238}U and ^{232}Th series.

Radionuclide	T	$E_{\beta j}$(max) (MeV)	k_j (%)	$R_{\beta j}$ (cm)
(a) Uranium series				
^{234}Th	24.1d day	0.1985	1	0.04105
^{234}Pa	6.75 h	0.5120	1	0.1616
^{214}Bi	19.9 m	1.5100	1	0.6500
^{214}Pb	26.8 m	0.6500	1	0.2045
^{210}Bi	5.01 d	1.1615	1	0.4628
^{210}Pb	22.3 y	0.0150	1	0.00046
^{210}Tl	1.32 m	1.9700	1	0.8997
^{206}Tl	4.3 m	1.5340	1	0.6535
Radionuclide	T	$E_{\beta j'}$(max)	k'_j	$R_{\beta j'}$

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		(MeV)	(%)	(cm)
(b) Thorium series				
^{228}Ra	5.7 y	0.0400	1	0.00266
^{228}Ac	6.1 h	1.1100	1	0.4604
^{212}Pb	10.6 h	0.3307	1	0.0970
^{212}Bi	61 m	2.2560	0.64	1.0234
^{208}Tl	3.1 m	1.7960	1	0.7750

The term ½ (Eqs. 9 and 10) means that only half of the emitted alpha-particles inside a plant oil layer may lose their energies inside skin according to Fig. 2(a).

Annual equivalent doses to surface skin of 1cm^2 (epidermis) during an exposure time equals 1 year (Sv y^{-1} cm^{-2}), due to alpha-particles emitted by the ^{238}U and ^{232}Th series from the application of a plant oil sample by bathers in a spa room, are respectively given by:

$$H(U) = \sum_{j=1}^{8} H(j) \quad (7)$$

and

$$H(Th) = \sum_{j'=1}^{7} H(j') \quad (8)$$

d. A new dosimetric model for determining annual equivalent doses to skin due to beta-particles emitted by the ^{238}U and ^{232}Th series from the application of plant oil samples

There are eight beta minus emitting nuclei belonging to the ^{238}U radioactive series (^{210}Pb, ^{234}Th, ^{234}Pa, ^{214}Pb, ^{210}Bi, ^{214}Bi, ^{206}Tl and ^{210}Tl) and five beta minus emitting nuclei belonging to the ^{232}Th radioactive series (^{228}Ra, ^{212}Pb, ^{228}Ac, ^{208}Tl and ^{212}Bi) [12] (Table 3).

A beta-particle (β^-) of index j and initial energy $E_{\beta j}$ (max), emitted from a nucleus, belonging to the ^{238}U series, localized at the point P inside a plant oil material layer (Fig. 2(b)) has a range, $\overline{PF}$,

$$\overline{PF} = x_j + R_{\beta_j}^{skin} \quad (9)$$

where x_j ($x_j \le R_{\beta_j}$ and R_{β_j} is the range of the beta-particle in plant oil) is the distance between the point of emission and the skin (Fig. 2(b)) and $R_{\beta_j}^{skin}$ is the range of the beta-particle in skin.

The beta-particle residual energy $E_{\beta_j}^{Res}$, which corresponds to the (R_{β_j} - x_j) range, is determined by using the energy-range relationship in plant oil obtained by fitting the curve represented in Fig. 4(a). By using the energy–range relationship in skin (obtained by fitting the curve represented in Fig. 4(b)) one can determine the range of the beta-particle in skin $R_{\beta_j}^{Skin}$.

For $x_j = R_{\beta_j}$, $E_{\beta_j}^{Res} = 0\ MeV$; there is no energy loss of beta-particles in skin (case 1 of Fig. 2(b)).

For a beta-particle emitted at the surface of skin $x_j = 0\ \mu m$, $E_{\beta_j}^{Res} = E_{\beta_j}$; the energy loss of beta-particles in skin is maximum ($R_{\beta_j}^{Skin}$ maximum) (case 3 of Fig. 2(b)). For $x_j < R_{\beta_j}$, $E_{\beta_j}^{Res} < E_{\beta_j}$; the ranges of beta-particles in skin are lower than those corresponding to $x_j = 0\ \mu m$ (case 2 of Fig. 2(b)).

Similarly a beta-particle (β^-) of index j' and initial energy $E_{\beta j'}$ (max), emitted from a nucleus, belonging to the ^{232}Th series, localized at the point P inside a plant oil material layer (Fig. 2b) has a range, $\overline{PF}$,

$$\overline{PF} = x_{j'} + R_{\beta_{j'}}^{skin} \quad (10)$$

where $x_{j'}$ ($x_{j'} \le R_{\beta_{j'}}$ and $R_{\beta_{j'}}$ is the range of the beta-particle in plant oil) is the distance between the point of emission and the skin (Fig. 2(b)) and $R_{\beta_{j'}}^{skin}$ is the range of the beta-particle in skin.

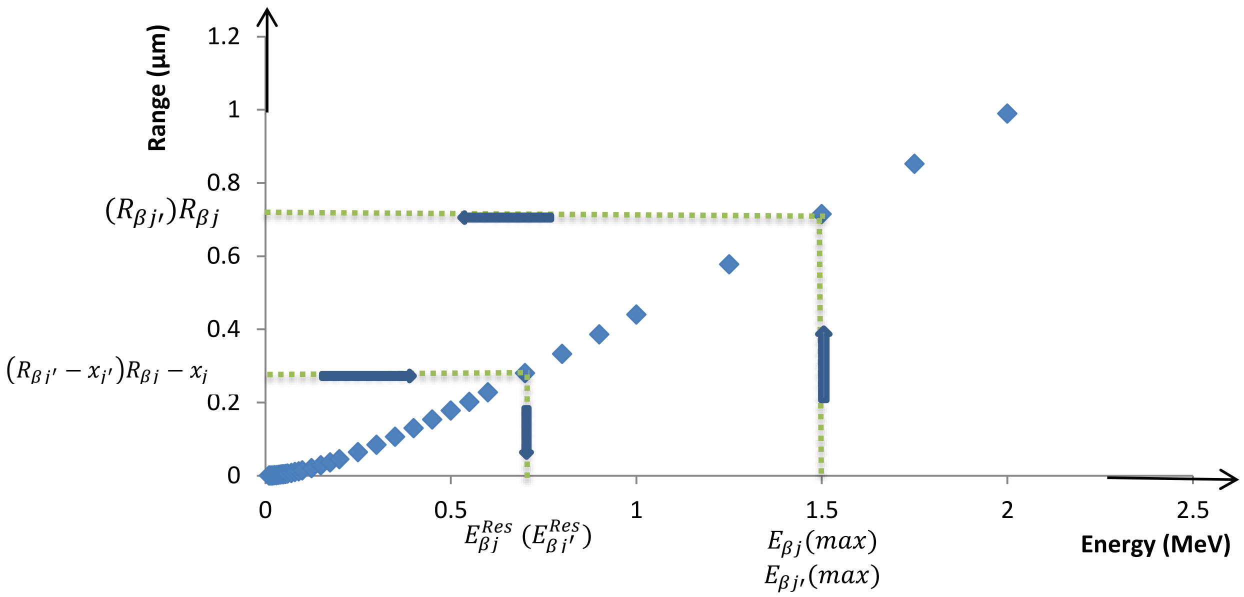

Fig 4(a)

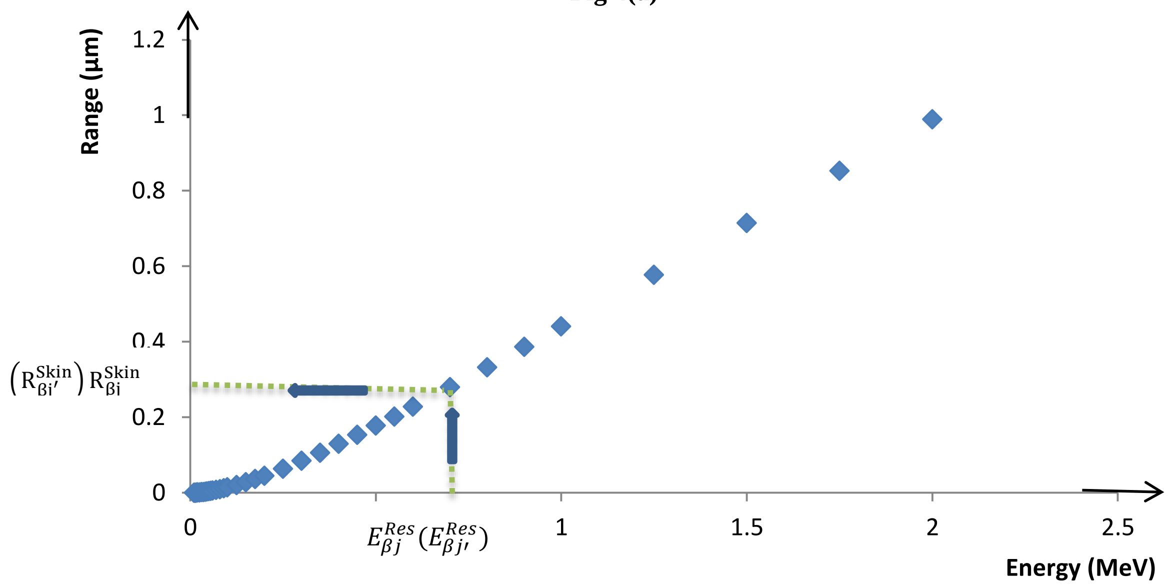

Fig. 4(b)

Fig. 4. Variation of beta-particle range as a function of beta-particle energy in plant oil (a) and skin (b).

The beta-particle residual energy $E^{Res}_{\beta_j'}$, which corresponds to the ($R_{\beta_j'}$ - $x_{j'}$) range, is determined by using the energy-range relationship in plant oil obtained by fitting the curve represented in Fig. 4(a). By using the energy–range relationship in skin (obtained by fitting the curve represented in Fig. 4(b)) one can determine the range of the beta-particle in skin $R^{Skin}_{\beta_j'}$.

For $x_{j'} = R_{\beta_{j'}}$, $E^{Res}_{\beta_j'} = 0\ MeV$; there is no energy loss of beta-particles in skin (case 1 of Fig. 2(b)).

For a beta-particle emitted at the surface of skin $x_{j'} = 0\ \mu m$, $E^{Res}_{\beta_j'} = E_{\beta_j'}$; the energy loss of beta-particles in skin is maximum ($R^{Skin}_{\beta_j'}$ maximum) (case 3 of Fig. 2(b)). For $x_{j'} < R_{\beta_{j'}}$, $E^{Res}_{\beta_{j'}} < E_{\beta_{j'}}$; the ranges of beta-particles in skin are lower than those corresponding to $x_{j'} = 0\ \mu m$ (case 2 of Fig. 2(b)).

The ranges of beta-particles emitted by the nuclei of the ^{238}U and ^{232}Th series in essential plant oil samples and skin were calculated by using an ESTAR code [13] and composition data for skin [11] (Table 3).

Beta equivalent dose rates (Sv s^{-1}) to the human skin due to a radionuclide of index j belonging to the ^{238}U series and a radionuclide of index j' belonging to the ^{232}Th series present in a plant oil sample are respectively given by:

$$\dot{H}_{skin}(j,t) = A_C^{skin}(j,t) D_{sp}^{skin}(j) W_R \quad (11)$$

and

$$\dot{H}_{skin}(j',t) = A_C^{skin}(j',t) D_{sp}^{skin}(j') W_R \quad (12)$$

where $A_c^{skin}(j,t)$ (Bq) is the activity, at time t, in 1 cm^3 of skin due to a radionuclide of index j belonging to the ^{238}U series, $A_c^{skin}(j',t)$ (Bq) is the activity, at time t, in 1 cm^3 of skin due to a radionuclide of index j' belonging to the ^{223}Th series, $D_{Sp}^{skin}(j)$ is the specific beta dose (Gy) deposited by 1Bq of a radionuclide of index j belonging to the ^{238}U series in skin, $D_{Sp}^{skin}(j')$ is the specific beta dose (Gy) deposited by 1Bq of a radionuclide of index j' belonging to the ^{232}Th series in skin and W_R is the radiation weighting factor which is equal to 1 for beta-particles [11].

The $A_c^{skin}(j,t)$ and $A_c^{skin}(j',t)$ activities are respectively given by:

$$A_c^{skin}(j,t) = \frac{1}{2} A_c^{plantoil}\left(^{238}U\right) e^{-\lambda_j t} \text{ x1cm}^3 \quad (13)$$

and

$$A_c^{skin}(j',t) = \frac{1}{2} A_c^{plantoil}\left(^{232}Th\right) e^{-\lambda_{j'} t} \text{ x1cm}^3 \quad (14)$$

where $A_c^{plantoil}\left(^{238}U\right)$ (Bq cm^{-3}) is the activity due to ^{238}U inside a plant oil sample, $A_c^{plantoil}\left(^{232}Th\right)$ (Bq cm^{-3}) is the activity due to ^{232}Th inside a plant oil sample, λ_j is the radioactive decay constant of a radionuclide of index j belonging to the ^{238}U series and $\lambda_{j'}$ is the radioactive decay constant of a radionuclide of index j' belonging to the ^{232}Th series. The term ½ (Eqs. 13 and 14) means that only half of the emitted beta-particles inside a plant oil layer may lose their energies inside the skin according to Fig. 2(b).

The $D_{Sp}^{skin}(j)$ and $D_{Sp}^{skin}(j')$ specific beta doses are respectively given by:

$$D_{sp}^{skin}(j) = k \frac{k_{\beta j}}{\rho_{skin} S_{skin}} \frac{E_{\beta j}^{Res}}{R_{\beta j}^{skin}} \quad (15)$$

and

$$D_{sp}^{skin}(j') = k \frac{k'_{\beta j}}{\rho_{skin} S_{skin}} \frac{E_{\beta j'}^{Res}}{R_{\beta j'}^{skin}} \quad (16)$$

where $k_{\beta j}$ and $k'_{\beta j}$ are respectively the branching ratios corresponding to the beta disintegration of the nuclei of the ^{238}U and ^{232}Th series, ρ_{skin} is the density of skin (g cm^{-3}), S_{skin} is the skin surface (cm^2), k = 1.6.10^{-13} (J MeV^{-1}) is a conversion factor, $R_{\beta_j}^{skin}$ is the range, in skin, of a beta-particle of index j and residual energy $E_{\beta_j}^{Res}$ belonging to the ^{238}U series and $R_{\beta_{j'}}^{skin}$ is the range, in skin, of a beta-particle of index j' and residual energy $E_{\beta_{j'}}^{Res}$ belonging to the ^{232}Th series (Fig. 4b).

By integrating Eqs. 11 and 12 over time, committed equivalent doses (Sv) to skin due to a beta-particle of residual energy $E_{\beta_j}^{Res}$ emitted by a radionuclide of index j belonging to the ^{238}U series and a beta-particle of residual energy $E_{\beta j'}^{Res}$ emitted by a radionuclide of index j' belonging to the ^{232}Th series are respectively given by:

$$H_{skin}(j) = \frac{D_{sp}^{skin}(j)\ W_R}{2\lambda_J} A_C^{plantoil}\left(^{238}U\right)\left(1 - e^{-\lambda_J t_e}\right) \quad (17)$$

and

$$H_{skin}(j') = \frac{D_{sp}^{skin}(j')\ W_R}{2\lambda_{j'}} A_C^{plantoil}\left(^{232}Th\right)\left(1 - e^{-\lambda_{j'} t_e}\right) \quad (18)$$

where t_e is the exposure time.

Committed equivalent doses to skin (Sv) due to all residual energies of a beta-particle of index j and initial energy $E_{\beta j}$(max) belonging to the ^{238}U series and a beta-particle of index j' and initial energy $E_{\beta j'}$(max) belonging to the ^{232}Th series are respectively given by:

$$H(j) = \frac{k K_j A_c^{PO}(^{238}U))\left(1-e^{-\lambda_j t_a}\right)}{2\lambda_j \rho_{skin} S_{skin} \Delta E_{\beta j}^{Res}} \int_0^{E_{\beta j}} \frac{E_{\beta j}^{Res}}{R_{\beta j}^{skin}(E_{\beta j}^{Res})} dE_{\beta j}^{Res}$$

$$H(j) = \frac{k\, k_{\beta j} A_c^{plantoil}(^{238}U)(1-e^{-\lambda_j t_e})}{2\lambda_j \rho_{skin}\ S_{skin} \Delta E_{\beta j}^{Res}} \int_0^{E_{\beta j}(max)} \frac{E_{\beta j}^{Res}}{R_{\beta j}^{skin}(E_{\beta j}^{Res})} dE_{\beta j}^{Res} \quad (19)$$

and

$$H(j') = \frac{k\, k'_{\beta j}\ A_c^{plantoil}(^{232}Th)(1-e^{-\lambda_{j'} t_e})}{2\lambda_j \rho_{skin} S_{skin} \Delta E_{\beta j'}^{Res}} \int_0^{E_{\beta_{j'}}(max)} \frac{E_{\beta j'}^{Res}}{R_{\beta j'}^{skin}(E_{\beta j'}^{Res})} dE_{\beta j'}^{Res} \quad (20)$$

where t_e is the application time of plant oils by bathers inside spa rooms and $\Delta E_{\beta_j}^{Res}$ and $\Delta E_{\beta_{j'}}^{Res}$ are respectively the chosen steps on the [0-$E_{\beta j}$(max)] and [0-$E_{\beta j'}$(max)] energy intervals.

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Annual equivalent doses to surface skin of 1cm^2 (epidermis, dermis and hypodermis) during an exposure time equals 1 year (Sv y^{-1} cm^{-2}), due to beta-particles emitted by the ^{238}U and ^{232}Th series from the application of a plant oil sample by bathers in spa rooms, are respectively given by:

$$H(U) = \sum_{j=1}^{8} H(j) \quad (21)$$

and

$$H(Th) = \sum_{j'=1}^{5} H(j') \quad (22)$$

3. RESULTS AND DISCUSSION

a. ^{238}U, ^{232}Th, ^{222}Rn and ^{220}Rn concentrations inside different essential plant oil samples

The ^{238}U (A_c (^{238}U)) and ^{232}Th (A_c (^{232}Th)) contents have been determined in different essential plant oil samples, utilized by bathers in spa rooms, by using Eqs. 1 and 2. The obtained results are given in Table 4. The relative uncertainty of the ^{238}U and ^{232}Th content evaluation varies between 4 % and 8 %. Minimum detection activities (MDA) for ^{238}U and ^{232}Th were found equal to (0.81±0.05) mBq kg^{-1} and (0.11±0.01) mBq kg^{-1}, respectively.

It is to be noted from data shown in Table 4 that:

- All the studied plant oil samples contain more ^{238}U than ^{232}Th. This is obviously due to the fact that their corresponding plants contain more uranium than thorium.
- The PO 16 (Salvia sidi rheat) and PO19 (L'olivier) plant oil samples show higher ^{238}U concentrations than the other plant oil samples. This is because their corresponding plants (salvia and L'olivier) contain more ^{238}U and ^{232}Th than those corresponding to other plant oil samples.
- The ^{238}U and ^{232}Th concentrations ranged between 34.0 mBq kg^{-1} and 80.5 mBq kg^{-1} and between 3.5 mBq kg^{-1} and 12.5 mBq kg^{-1} for the studied plant oil samples, respectively.
- Nine essential plant oil samples were analyzed by using isotope dilution mass spectrometry (IDMS). Results obtained by the two methods, for ^{238}U and ^{232}Th concentrations, are in good agreement with each other (Table 4).

Table 4. Data obtained for the ^{238}U and ^{232}Th contents inside different essential plant oil samples by using the SSNTD's method (Misdaq et al. 2000) and the Isotope Dilution Mass Spectrometry (IDMS).

		SSNTD's method				IDMS	
Plant oil	Plant	ρ_G^{LR} (10^{-4}tr.cm^{-2}.s^{-1})	ρ_G^{CR} (10^{-4}tr.cm^{-2}.s^{-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})
PO1	Romarin	1. 3±0.1	5.7±0.3	42±3	7.8±0.5	43±2	8.0±0.2
PO2	Feuilno	1.4±0.1	6.1 ±0.4	45±3	8.0±0.5		
PO3	Saturja	2.1±0.1	8.8±0.5	68±5	10.5±0.6		
PO4	Ammi khella	1.2±0.1	5.2±0.3	42±3	70.0±5.0		
PO5	Armoise	1.1±0.1	5.1±0.3	34±2	7.8±0.5	35±1	7.6±0.3
PO6	Rue ousoudab	1.3±0.1	5.6±0.3	42±3	6.8±0.4		
PO7	Origon	1.2±0.1	4.9±0.3	40±2	6.0±0.4		
PO8	ChloroLhyle	1.2±0.1	4.5±0.3	42±2	4.2±0.2		
PO9	EucalyLtus	1.1±0.1	4.1±0.2	38±3	3.5±0.2	40±1	3.7±0.1
PO10	Thya	1.2±0.1	4.6±0.3	43±3	4.6 ±0.3		

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PO11	Absinthe	1.3±0.1	5.3±0.3	45±3	6.0 ±0.4		
PO12	EuLhorbe resinefere	1.5±0.1	6.3±0.4	50±4	8.0±0.5	48±2	7.8±0.3
PO13	Nigelle	1.1±0.1	4.1±0.3	38±3	3.5±0.2		
PO14	Verveine	1.8±0.1	8.3±0.5	56±4	12.5±1.0	52±2	11.8±0.4
PO15	EuLhorbe cactoide	1.6±0.1	7.1±0.4	52±3	10.0±0.8	54±2	10.4±0.4
PO16	Salvia sidi rheat	2.2±0.1	7.8±0.6	78±6	5.0±0.3	80±3	5.4±0.2
PO17	Sousi Officinal	1.2±0.1	4.5±0.3	42±3	4.3±0.3		
PO18	Lavande Officinal	1.3±0.1	5.7±0.3	41±3	7.8±0.5		
PO19	L'olivier	2.4±0.2	9.6±0.6	80±6	10.5±0.6	82±4	10.2±0.6
PO20	Arganier	1.4±0.1	5.7±0.3	46±3	5.8±0.3	44±1	6.0±0.2

b. Annual equivalent doses to the skin of bathers due to alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series from the application of different essential plant oil samples in spa rooms

A census of the essential plant oils used by adult male bathers inside spa rooms was taken. Twenty groups of bathers were identified: 351, 175, 225, 480, 136, 299, 301, 166, 125, 273, 521, 188, 312, 102, 246, 155, 276, 82, 413, and 315 bathers using the PO1, PO2, PO3, PO4, PO5, PO6, PO7, PO8, PO9, PO10, PO11, PO12, PO13, PO14, PO15, PO16, PO17, PO18, PO19, and PO20 essential plant oils, respectively (Tables 5-8).

Annual equivalent doses to skin due to the alpha-emitting nuclei of the ^{238}U and ^{232}Th series from the application of different essential plant oil samples by adult male bathers in four spa rooms at identical temperature (40°C) and pressure (968.7 hPa) have been evaluated by means of Eqs. 11 and 12 as shown in Tables 5 and 6. The statistical relative uncertainty of the annual equivalent dose determination ranged between 7 % and 10 %. It is to be noted from results shown in Tables 5 and 6 that annual equivalent doses to the skin of adult male bathers due to alpha-particles emitted by ^{214}Po (H (^{214}Po)) and ^{218}Po (H (^{218}Po)) are negligible compared to those corresponding to the other alpha-emitters of the ^{238}U series. This is because these radionuclides have smaller half-lives, 1.6 10^{-4} s and 3.05 min, respectively than the other radionuclides (Table 2). Also, one can note that alpha committed equivalent doses to the skin of adult male bathers due to ^{232}Th (H (^{232}Th)), ^{228}Th (H (^{228}Th)), and ^{224}Ra (H (^{232}Th)) are clearly higher than those due to the other radionuclides of the ^{232}Th series. This is due to the fact that these radionuclides possess higher half-lives, 1.4 10^{10} y and 1.190 y, respectively than the other alpha-emitters of the ^{232}Th series (Table 2). It is to be noted that alpha equivalent doses due to the radionuclides of the ^{238}U series are clearly higher than those due to the radionuclides of the ^{232}Th series from the application of the studied essential oil samples by adult bathers according to Eqs. 11 and 12 (Tables 5 and 6). This is because the studied plant oil samples contain more ^{238}U than ^{232}Th (Table 4). Even if ^{238}U has a higher half-life than ^{226}Ra, annual equivalent doses due to ^{226}Ra are larger than those due to ^{238}U.This because alpha-particles emitted by ^{226}Ra have higher initial energy than those emitted by ^{238}U (Table 2). Even though ^{232}Th has a higher half-life than ^{228}Th, and ^{224}Ra, annual equivalent doses due to these radionuclides are larger than that due ^{232}Th. This is due to the fact that alpha-particles emitted by these radionuclides have higher initial energies than those emitted by ^{232}Th (Table 2). One can note that total annual equivalent doses to the skin of adult male bathers due to the radionuclides of the ^{238}U (H_α(U)) and ^{232}Th (H_α(Th)) series increase with the ^{238}U than ^{232}Th contents inside the studied plant oil samples, respectively (Tables 5 and 6). H_α(U) ranged between 89 and 364 μSv y^{-1} cm^{-2} while H_α(Th) ranged between 43 and 206 μSv y^{-1} cm^{-2}. One can conclude from data shown in Tables 4 and 5 that total annual equivalent doses to the skin of bathers due to alpha-particles emitted by the ^{238}Uand ^{232}Th increase with the exposure time (2 h and 4 h per week).

c. Annual equivalent doses to skin of bathers due to beta-particles emitted by the nuclei of the ^{238}U, ^{232}Th series from the application of essential plant oil samples in spa rooms

Annual equivalent doses to skin due to beta- particles emitted by the radionuclides of the ^{238}U (H_β (U)) and ^{232}Th (H_β (Th)) series from the application of various plant oil samples by adult male bathers in spa rooms have been evaluated by means of Eqs. 25 and 26 as shown in Tables 7 and 8. The statistical relative uncertainty of the committed equivalent dose determination ranged between 8 % and 10 %. H_β (U) ranged between 2 and 8.68 μSv y^{-1} cm^{-2} while H_β (Th) ranged between 0.9 and 3.5 μSv y^{-1} cm^{-2}. It is to be noted that total committed equivalent doses to the skin of bathers due to beta-particles emitted by the radionuclides of the ^{232}Th series (H_β (Th)) are clearly lower than those due to beta-particles emitted by the ^{238}U series (H_β (U)) (Tables 7 and 8). This is because the studied plant oil samples contain more ^{238}U than ^{232}Th (Table 1). One can note that committed equivalent doses to the skin of adult bathers due to beta-particles emitted by the ^{234}Th, ^{210}Bi, and ^{210}Pb radionuclides of the ^{238}U series are clearly higher than those due to the ^{234}Pa, ^{214}Bi, ^{214}Pb, ^{210}Tl and ^{206}Tl radionuclides of the ^{238}U series (Tables 7 and 8). This is due to the fact that the former radionuclides have higher half-lives (24.1 d and 5.01 d and 22.3 y, respectively) than the latter radionuclides (Table 3). Even though ^{210}Pb has a longer half-life than ^{234}Th, committed equivalent dose to the skin of adult bathers due beta-particles emitted by these radionuclides are practically similar. There is compensation between the effects of half-life and beta maximum energy (Table 4). One can also note that committed equivalent dose to the skin of adult bathers due to beta-particles emitted by ^{228}Ra is clearly higher than those due to the other radionuclides of the ^{232}Th series although it has the lowest beta maximum energy. This due to the fact that this radionuclide has a higher half-life (5.7 y) than the other radionuclides of the ^{232}Th series (Table 4): there is predominance of the radionuclide half-life. One can note that total committed equivalent doses to skin due to the radionuclides of the ^{238}U and ^{232}Th series increase with the exposure time of bathers in spa rooms (Tables 7 and 8).

Table 5 (a). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of an alpha-particle of index j and initial energy $E_{\alpha j}$ belonging to the ^{238}U series from the application of different plant oil samples in spa rooms. H_α(U) is the total annual equivalent dose due to the radionuclides of the ^{238}U series. The application time is 2 hours per week.

Plant oil	Plant	H (^{238}U) (10^{-8}Sv y^{-1} cm^{-2})	H (^{230}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{234}U) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{226}Ra) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{210}Po) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{222}Rn) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{218}Po) (10^{-9}Sv $y^{-1}cm^{-2}$)	H(^{214}Po) (10^{-15}Sv $y^{-1}cm^{-2}$)	H_α(U) (μSv $y^{-1}cm^{-2}$)
PO1	Romarin	1529	1670	1715	1720	1866	1379	15.99	16.94	98±7
PO2	Feuilno	1638	1790	1838	1843	2000	1478	17.13	18.15	105±8
PO3	Saturja	2476	2705	2778	2786	3022	2233	25.89	27.42	160±12
PO4	Ammi khella	1529	1670	1715	1720	1866	1379	15.99	16.94	98±7
PO5	Armoise	1238	1352	1389	1393	1511	1116	12.94	13.71	80±6
PO6	Rue ousoudab	1529	1670	1715	1720	1866	1379	15.99	16.94	98±7
PO7	Origon	1467	1603	1646	1651	1791	1323	15.34	16.25	94±7
PO8	Chlorolhyle	1529	1670	1715	1720	1866	1379	15.99	16.94	98±7
PO9	Eucalyltus	1383	1511	1552	1557	1689	1248	14.47	15.32	89±7
PO10	Thya	1565	1710	1756	1761	1911	1412	16.37	17.34	101±7
PO11	Absinthe	1638	1790	1838	1843	2000	1478	17.13	18.15	105±8
PO12	Eulhorbe resinefere	1820	1989	2042	2048	2222	1642	19.04	20.16	117±9
PO13	Nigelle	1383	1511	1552	1557	1689	1248	14.47	15.32	89±7
PO14	verveine	2039	2227	2287	2294	2489	1839	21.32	22.58	131±10
PO15	Eulhorbe cactoide	1911	2088	2144	2151	2333	1724	19.99	21.17	123±9
PO16	Salvia sidi rheat	2840	3103	3186	3196	3466	2561	29.70	31.46	183±16
PO17	Sousi officinal	1529	1670	1715	1720	1866	1379	15.99	16.94	98±8
PO18	Lavande officinal	1507	1647	1691	1696	1840	1359	15.76	16.69	97±8
PO19	L'olivier	2931	3202	3288	3298	3578	2644	30.65	32.47	189±15
PO20	Arganier	1674	1830	1879	1884	2044	1510	17.51	18.55	108±8

Table 5 (b). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of an alpha-particle of index j and initial energy $E_{\alpha j}$ belonging to the ^{232}Th series from the application of different plant oil samples in spa rooms. H_α(Th) is the total annual equivalent dose due to the radionuclides of the ^{232}Th series. The application time is 2 hours per week

Plant Oil	Plant	H (^{232}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{228}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{224}Ra) (10^{-8}Sv. y^{-1} cm^{-2})	H(^{212}Bi) (10^{-9}Sv y^{-1} cm^{-2})	H(^{220}Rn) (10^{-9}Sv $y^{-1}cm^{-2}$)	H(^{216}Po) (10^{-12}Sv y^{-1} cm^{-2})	H(^{212}Po) (10^{-18}Sv $y^{-1}cm^{-2}$)	H_α(Th) (µSv y^{-1} cm^{-2})
PO1	Romarin	1468	1912	2000	115	4.99	15.21	27.63	53±4
PO2	Feuilno	1573	2049	2143	123	5.34	16.30	29.61	57±4
PO3	Saturja	2377	3097	3238	186	1.86	24.63	44.74	87±8
PO4	Ammi khella	1468	1912	2000	115	4.99	15.21	27.63	53±4
PO5	Armoise	1188	1548	1619	93.08	4.04	12.31	22.37	43±4
PO6	Rue ousoudab	1468	1912	2000	115	4.99	15.21	27.63	53±4
PO7	Origon	1409	1835	1919	110	4.79	14.60	26.52	51±4
PO8	Chlorolhyle	1469	1914	2001	115	4.99	15.22	27.65	54±5
PO9	Eucalyltus	1328	1730	1809	104	4.51	13.76	25	48±4
PO10	Thya	1503	1958	2048	117	5.11	15.57	28.29	55±4
PO11	Absinthe	1573	2049	2143	123.20	5.34	16.30	29.61	57±5
PO12	Eulhorbe resinefere	1748	2277	2381	136.89	5.94	18.11	32.90	64±5
PO13	Nigelle	1328	1730	1809	104	4.51	13.76	25	49±4
PO14	Verveine	1958	2550	2667	153.32	6.65	20.02	36.82	71±5
PO15	Eulhorbe cactoide	1835	2391	2500	143.74	6.24	19.02	34.54	67±5
PO16	Salvia sidi rheat	2727	3552	3715	213.55	9.27	28.25	51.33	100±8
PO17	Sousi officinal	1468	1912	2000	115	4.99	15.21	27.63	54±4
PO18	Lavande officinal	1447	1885	1971	113.34	4.92	14.99	27.24	53±4
PO19	L’olivier	2814	3666	3834	220.40	9.57	29.16	52.97	103±9
PO20	Arganier	1608	2095	2190	125.94	5.46	16.66	30.27	59±4

Table 6 (a). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of an alpha-particle of index j and initial energy $E_{\alpha j}$ belonging to the ^{238}U series from the application of different plant oil samples in spa rooms. H_α(U) is the total annual equivalent dose due to the radionuclides of the ^{238}U series. The application time is 4 hours per week.

Plant Oil	Plant	H (^{238}U) (10^{-8}Sv y^{-1} cm^{-2})	H (^{230}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{234}U) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{226}Ra) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{210}Po) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{222}Rn) (10^{-8}Sv $y^{-1}cm^{-2}$)	H(^{218}Po) (10^{-9}Sv $y^{-1}cm^{-2}$)	H(^{214}Po) (10^{-15}Sv $y^{-1}cm^{-2}$)	H_α(U) (µSv $y^{-1}cm^{-2}$)
PO1	Romarin	3058	3340	3437	3441	3705	2049	15.99	16.94	190±15
PO2	Feuilno	3277	3578	3683	3687	3970	2195	17.13	18.15	203±18
PO3	Saturja	4952	5407	5565	5572	5999	3317	25.89	25.89	308±27
PO4	Ammi khella	3058	3340	3437	3441	3705	2049	15.99	16.94	190±15
PO5	Armoise	2476	2703	2782	2786	2999	1658	12.94	13.71	154±11
PO6	Rue ousoudab	3058	3340	3437	3441	3705	2049	15.99	16.41	190±15
PO7	Origon	2934	3204	3298	3302	3555	1966	15.34	16.25	182±16

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PO8	Chlorolhyle	3058	3340	3437	3441	3705	2049	15.99	16.94	190±16
PO9	Eucalyltus	2767	3021	3110	3114	3352	1854	14.47	15.32	172±12
PO10	Thya	3131	3419	3519	3523	3793	2098	16.37	17.34	194.±19
PO11	Absinthe	3277	3578	3683	3687	3970	2195	17.13	18.15	203±20
PO12	Eulhorbe resinefere	3641	3976	4092	4097	4411	2439	19.04	20.16	226±22
PO13	Nigelle	2767	3021	3110	3114	3352	1854	14.47	15.32	172±15
PO14	verveine	4078	4453	4583	4589	4940	2732	21.32	22.58	253±24
PO15	Eulhorbe cactoide	3823	4175	4296	4302	4632	2561	19.99	21.17	237±23
PO16	Salvia sidi rheat	5680	6202	6383	6392	6881	3805	29.7	31.46	353±31
PO17	Sousi officinal	3058	3340	3437	3441	3705	2049	15.99	16.94	190±15
PO18	Lavande officinal	3014	3292	3388	3392	3652	2019	15.76	16.69	187±15
PO19	L'olivier	5862	6401	6588	6597	7102	3927	30.65	32.47	364±36
PO20	Arganier	3349	3658	3764	3769	4058	2244	17.51	18.55	208±18

Table 6 (b). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of an alpha-particle of index j and initial energy $E_{\alpha j}$ belonging to the ^{232}Th series from the application of different plant oil samples in spa rooms. H_α(Th) is the total annual equivalent dose due to the radionuclides of the ^{232}Th series. The application time is 4 hours per week

Plant oil	Plant	H (^{232}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{228}Th) (10^{-8}Sv y^{-1} cm^{-2})	H(^{224}Ra) (10^{-8}Sv. y^{-1} cm^{-2})	H(^{212}Bi) (10^{-9}Sv y^{-1} cm^{-2})	H(^{220}Rn) (10^{-9}Sv $y^{-1}cm^{-2}$)	H(^{216}Po) (10^{-12}Sv y^{-1} cm^{-2})	H(^{212}Po) (10^{-18}Sv $y^{-1}cm^{-2}$)	H_α(Th) (μSv y^{-1} cm^{-2})
PO1	Romarin	2937	3818	3998	114.9	4.99	15.21	27.63	107±8
PO2	Feuilno	3146	4091	4284	123.2	5.34	16.30	29.61	115±10
PO3	Saturja	4755	6182	6473	186.17	8.08	24.63	44.74	174.±15
PO4	Ammi khella	2937	3818	3998	114.99	4.99	15.21	27.63	107±9
PO5	Armoise	2377	3091	3236	93.08	4.04	12.31	22.37	87±6
PO6	Rue ousoudab	2937	3818	3998	114.99	4.99	15.21	27.63	107±8
PO7	Origon	2818	3663	3836	110.33	4.79	14.60	26.52	103±9
PO8	Chlorolhyle	2937	3818	3998	114.99	4.99	15.21	27.63	107±9
PO9	Eucalyltus	2657	3454	3617	104.04	4.51	13.76	25	97±7
PO10	Thya	3007	3909	4093	117.73	5.11	15.57	28.29	110±10
PO11	Absinthe	3146	4091	4284	123.20	5.34	16.30	29.61	115±9
±PO12	Eulhorbe resinefere	3496	4545	4760	136.89	5.94	18.11	32.90	128±9
PO13	Nigelle	2657	3454	3617	104.04	4.51	13.76	25	97±7
PO14	verveine	3916	5091	5331	153.32	6.65	20.28	36.85	143±11
PO15	Eulhorbe cactoide	3671	4773	4998	143.74	6.24	19.02	34.54	134±10
PO16	Salvia sidi rheat	5454	7091	7425	213.55	9.27	28.25	51.33	200±19
PO17	Sousi officinal	2937	3818	3998	114.99	4.99	15.21	27.63	107±7
PO18	Lavande officinal	2895	3763	3941	113.34	4.92	14.99	27.24	106±8
PO19	L'olivier	5629	7318	7663	220.4	9.57	29.16	52.97	206±16
PO20	Arganier	3216	4182	4379	125.94	5.46	16.66	30.27	117±10

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Table 7 (a). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of a beta-particle of index j and initial energy $E_{\beta j}$ (max) belonging to the ^{238}U series from the application of different plant oil samples in spa rooms. H_{β} (U) is the total annual equivalent dose due to the radionuclides of the ^{238}U series. The application time is 2 hours per week.

Plant oil	Plant	H(^{210}Pb) (10^{-7} Sv y-1 cm^{-2})	H(^{234}Th) (10^{-7} Sv y-1 cm^{-2})	H(^{234}Pa) (10^{-10} (Sv y-1 cm^{-2})	H(^{214}Pb) (10^{-9} Sv y-1 cm^{-2})	H(^{210}Bi) (10^{-7} Sv y-1 cm^{-2})	H(^{214}Bi) (10^{-9} Sv y-1 cm^{-2})	H(^{206}Tl) (10^{-10} (Sv y-1 cm^{-2})	H(^{210}Tl) (10^{-10} Sv y-1 cm^{-2})	H_{β}(U) (10^{-6} Sv y-1 cm^{-2})
PO1	Romarin	8.33	8.59	2.75	6.32	7.87	5.28	5.97	3.46	2.4±0.2
PO2	Feuilno	8.93	9.21	2.95	6.77	8.44	5.66	6.40	3.71	2.6±0.2
PO3	Saturja	13.49	13.39	4.46	10.23	12.75	8.55	9.67	5.61	3.9±0.3
PO4	Ammi khlla	8.33	8.59	2.75	6.32	7.87	5.28	5.97	3.46	2.4±0.2
PO5	Armoise	6.74	6.96	2.23	5.11	6.33	4.27	4.83	2.80	2.0±0.2
PO6	Rue ousoudab	8.33	8.59	2.75	6.32	7.87	5.28	5.97	3.46	2.4±0.2
PO7	Origon	7.99	8.25	2.64	6.06	7.55	5.07	5.73	3.32	2.3±0.2
PO8	Chlorolhyle	8.33	8.59	2.75	6.32	7.87	5.28	5.97	3.46	2.4±0.2
PO9	Eucalytus	7.54	7.78	2.49	5.72	7.12	4.78	5.40	3.13	2 .2±0.2
PO10	Thaya	8.53	8.80	2.82	6.47	8.06	5.41	6.11	3.55	2.5±0.2
PO11	Absinthe	8.93	9.21	2.95	6.77	8.44	5.66	6.40	3.71	2.6±0.2
PO12	EuLhorbe resinefere	9.92	10.23	3.28	7.52	9.37	6.29	7.11	4.13	2.9±0.2
PO13	Nigelle	7.54	7.78	2.49	5.72	7.12	4.78	5.40	3.13	2.2±0.2
PO14	Verveine	11.13	11.46	3.67	8.43	10.50	7.04	7.96	4.62	3.3±0.3
PO15	EuLhorbe cactoide	10.41	10.74	3.44	7.90	9.84	6.60	7.46	4.33	3.1±0.3
PO16	Salvia sidi rheat	15.47	15.97	5.11	11.74	14.63	9.81	11.00	6.44	4.6±0.4
PO17	Sousi Officinal	8.33	8.59	2.75	6.32	7.87	5.28	5.97	3.46	2.4±0.2
PO18	Lavande Officinal	8.21	8.47	2.71	6.23	7.75	5.21	5.88	3.41	2.4±0.2
PO19	L'olivier	15.97	16.48	5.28	12.12	15.09	10.13	11.40	6.64	4.7±0.4
PO20	Arganier	9.12	9.41	3.01	6.92	8.62	5.79	6.54	3.79	2.7± 0.2

Table 7 (b). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of a beta-particle of index j and initial energy $E_{\beta j}$ (max) belonging to the ^{232}Th series from the application of different plant oil samples in spa rooms. H_{β} (Th) is the total annual equivalent dose due to the radionuclides of the ^{232}Th series. The application time is 2 hours per week.

Plant oil	Plant	H(^{228}Ra) (10^{-7} Sv y^{-1} cm^{-2})	H(^{212}Pb) (10^{-7} Sv y^{-1} cm^{-2})	H(^{228}Ac) (10^{-7} Sv y^{-1} cm^{-2})	H(^{208}TI) (10^{-10} Sv y^{-1} cm^{-2})	H(^{212}Bi) (10^{-8} Sv y-1 cm-^{2})	H_{β}(Th) (10^{-7} Sv y^{-1} cm^{-2})
PO1	Romarin	8.00	1.66	1.00	8.92	1.15	10.7±0.9
PO2	Feuilno	8.57	1.78	1.07	9.55	1.24	11.5±1.0
PO3	Saturja	8.57	1.78	1.07	9.55	1.24	11.5±1.0
PO4	Ammi khlla	8.00	1.65	1.00	8.92	1.15	10.7±0.9
PO5	Armoise	6.47	1.34	0.81	7.22	0.93	8.7±0.7
PO6	Rue ousoudab	8.00	1.66	1.00	8.92	1.15	10.7±0.9
PO7	Origon	7.67	1.60	0.96	8.55	1.11	10.3±0.9
PO8	Chlorolhy	8.00	1.66	1.00	8.92	1.15	10.7±0.9

PO9	Eucalytus	7.24	1.50	0.90	8.07	1.04	9.7±0.7
PO10	thaya	8.19	1.70	1.02	9.13	1.18	11.0±1.0
PO11	Absinthe	8.57	1.78	1.07	9.55	12.41	12.6±1.1
PO12	EuLhorbe resinefere	9.52	1.98	1.19	10.61	1.37	12.8±1.1
PO13	Nigelle	7.24	1.50	0.90	8.07	1.04	9.7±0.8
PO14	Verveine	10.67	2.22	1.33	11.89	1.54	14.3±1.2
PO15	EuLhorbe cactoide	10.00	2.08	1.25	11.15	1.44	13.4±1.2
PO16	Salvia sidi rheat	14.86	3.09	1.86	16.56	2.15	20.0±1.8
PO17	Sousi Officinal	8.00	1.66	1.00	8.92	1.15	10.7±0.9
PO18	Lavande Officinal	7.88	1.64	0.98	8.79	1.14	10.6±0.9
PO19	L'olivier	15.34	3.19	1.92	17.09	2.22	20.6±1.8
PO20	Arganier	6.64	1.83	1.10	9.87	1.28	9.6±0.8

Table 8 (a). Annual equivalent doses to the skin of bathers (Sv $y^{-1}cm^{-2}$) due to all residual energies of a beta-particle of index j and initial energy $E_{\beta j}$ (max) belonging to the ^{238}U series from the application of different plant oil samples in spa rooms. H_β (U) is the total annual equivalent dose due to the radionuclides of the ^{238}U series. The application time is 4 hours per week.

Plant oil	Plant	H(^{210}Pb) (10^{-6} Sv y-1 cm^{-2})	H(^{234}Th) (10^{-6} Sv y-1 cm^{-2})	H(^{234}Pa) (10^{-10} Sv y-1 cm^{-2})	H(^{214}Pb) (10^{-9} Sv y-1 cm^{-2})	H(^{210}Bi) (10^{-6} sv y-1 cm^{-2})	H(^{214}Bi) 10^{-9} (Sv y-1 cm^{-2})	H(^{206}Tl)(10^{-10} S v y-1 cm^{-2})	H(^{210}Tl) (10^{-10}sv y-1 cm^{-2})	H_β (U) (10^{-6} Sv y-1 cm^{-2})
PO1	Romarin	1.66	1.62	2.75	6.32	1.24	5.28	5.97	3.46	4.5±0.4
PO 2	Feuilno	1.78	1.74	2.95	6.77	1.33	5.66	6.40	3.71	4.8±0.4
PO 3	Saturja	2.69	2.63	4.46	10.23	2.00	8.55	9.67	5.61	7.3±0.7
PO 4	Ammi khlla	1.66	1.62	2.75	6.32	1.24	5.28	5.97	3.46	4.5±0.4
PO 5	Armoise	1.34	1.31	2.23	5.11	0.10	1.27	4.83	2.80	2.7±0.2
PO 6	Rue ousoudab	1.66	1.62	2.75	6.32	1.24	5.28	5.97	3.46	4.5±0.4
PO 7	Origon	1.66	1.62	2.75	6.32	1.24	5.07	5.73	3.32	4.5±0.4
PO 8	Chlorolhyle	1.66	1.62	2.75	6.32	1.24	5.28	5.97	3.46	4.5±0.4
PO 9	Eucalytus	1.50	1.47	2.49	5.72	1.12	4.78	5.40	3.13	4.0±0.4
PO 10	Thaya	1.70	1.66	2.82	6.47	1.27	5.41	6.11	3.55	4.6±0.5
PO 11	Absinthe	1.78	1.74	2.95	6.77	1.33	5.66	6.40	3.71	4.8±0.5
PO 12	EuLhorbe resinefere	1.98	1.93	3.28	7.52	1.47	6.29	7.11	4.13	5.3±0.5
PO 13	Nigelle	1.50	1.47	2.49	5.72	1.12	4.78	5.40	3.13	4.0±0.4
PO 14	Verveine	2.22	2.16	3.67	8.43	1.65	7.04	7.96	4.62	6.0±0.6
PO 15	EuLhorbe cactoide	2.08	2.03	3.44	7.90	1.55	6.60	7.46	4.33	5.6±0.6
PO 16	Salvia sidi rheat	3.09	3.02	5.11	11.74	2.30	9.81	1.10	6.44	8.4±0.8
PO17	Sousi Officinal	1.66	1.62	2.75	6.32	1.24	5.28	5.97	3.46	4.5±0.4
PO 18	Lavande Officinal	1.64	1.60	2.71	6.23	1.22	5.21	5.88	3.41	4.4±0.4
PO 19	L'olivier	3.19	3.11	5.28	12.12	2.37	10.01	11.40	6.64	8.6±0.8
PO 20	Arganier	1.82	1.78	3.01	6.92	1.35	5.79	65.40	37.90	4.9±0,4

Table 8 (b). Annual equivalent doses to the skin of bathers (Sv y^{-1}cm^{-2}) due to all residual energies of a beta-particle of index j and initial energy $E_{\beta j}$ (max) belonging to the ^{238}Th series from the application of different plant oil samples in spa rooms. H_β (Th) is the total annual equivalent dose due to the radionuclides of the ^{232}Th series. The application time is 4 hours per week.

Plant oil	Plant	H(^{228}Ra) (10^{-6} Sv y-^{1} cm^{-2})	H(^{212}Pb) (10^{-7} Sv y-^{1} cm^{-2})	H(^{228}Ac) (10^{-7} Sv y-^{1} cm^{-2})	H(^{208}TI) (10^{-10}Sv y^{-1} cm^{-2})	H(^{212}Bi) (10^{-8} Sv y^{-1} cm-^{2})	H_β (Th) (10^{-6} Sv y^{-1} cm^{-2})
PO1	Romarin	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 2	Feuilno	1.71	1.79	1.00	9.55	1.24	2.0±0.2
PO 3	Saturja	2.59	2.70	1.00	14.44	1.87	2.9±0.2
PO 4	Ammi khlla	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 5	Armoise	0.12	1.35	0.81	7.22	0.93	0.34±0.03
PO 6	Rue ousoudab	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 7	Origon	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 8	Chlorolhyle	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 9	Eucalytus	1.44	1.51	0.90	8.07	1.04	1.6±0.1
PO 10	thaya	1.63	1.71	1.02	9.13	1.18	1.9±0.1
PO 11	Absinthe	1.71	1.78	1.07	9.55	12.41	2.1±0.2
PO 12	EuLhorbe resinefere	1.90	1.98	1.19	10.61	1,37	2.2±0.2
PO 13	Nigelle	1.44	1.51	0.90	8.07	1.04	1.6±0.1
PO 14	Verveine	2.13	2.22	1.33	11.89	1.54	2.5±0.2
PO 15	EuLhorbe cactoide	2.00	2.08	1.25	11.50	1.44	2.3±0.2
PO 16	Salvia sidi rheat	2.29	3.10	1.86	16.65	2.15	2.8±0.2
PO17	Sousi Officinal	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 18	Lavande Officinal	1.60	1.67	1.00	8.92	1.15	1.8±0.1
PO 19	L'olivier	3.06	3.20	1.00	17.09	2.22	3.5±0.3
PO 20	Arganier	1.75	1.83	1.09	9.76	1.26	2.0±0.2

4. CONCLUSION

It has been shown in this study that by using CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) one can determine ^{238}U, and ^{232}Th concentrations in essential plant oil material samples used by bathers in spa rooms. New personalized external dosimetry models which take into account the surface of skin (age group) of bathers and the concentrations of ^{238}U and ^{232}Th inside the studied plant oil samples were developed for assessing radiation doses to skin due to the emitted alpha- and beta-particles. It has been shown that due to their ranges in skin, alpha-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series inside plant oil samples can deposit their energies in the sensitive basal layer of the epidermis of the skin of bathers in spa rooms. Due to their longer ranges in skin, beta-particles emitted by the radionuclides of the ^{238}U and ^{232}Th series in essential oil can deposit their energies in the deeper layers of skin of bathers. It has been shown that total committed equivalent doses to skin due to the radionuclides of the ^{238}U and ^{232}Th series from the application of essential oil samples by adult male bathers in spa rooms depend on the ^{238}U and ^{232}Th concentrations in plant oils and exposure time of bathers.

The SSNTD's method utilized is inexpensive, moderately accurate, and sensitive and does not need the use of standard sources for its calibration. It is of interest for measuring ^{238}U and ^{232}Th concentrations in pharmaceutical and cosmetic products. The personalized dosimetric models developed in this study are of interest for assessing beta and alpha radiation doses to the skin of individuals from the application of various creams and beauty products.

REFERENCES

[1] Misdaq, M. A., Ghilane, M., Ouguidi, J., and Outeqablit, K., 2012, "Radiation doses to individuals due to ^{238}U, ^{232}Th and ^{222}Rn from the immersion in thermal waters and to radon progeny from the inhalation of air inside thermal stations", Radiat. Environ. Biophys., 51, pp. 375-389.

[2] Misdaq, M. A., and Touti, R., 2012, "Annual committed effective dose from olive oil (due to ^{238}U, ^{232}Th, and ^{222}Rn) estimated for members of the Moroccan public from ingestion and skin application", Health Phys., 102, pp. 335-345.

[3] Misdaq MA, Matrane A (2016) ^{238}U and ^{232}Th concentrations measured in different medical drugs by using solid-state nuclear track detectors and resulting radiation doses to the skin of patients. Nucl Sci Tech 27:30-41

[4] Misdaq MA, Chaouqi A, Ouguidi J, Touti R, Mortassim A (2015) Measurement of ^{238}U and ^{232}Th in petrol, gas-oil and lubricant samples by using nuclear track detectors and resulting radiation doses to the skin of mechanic workers. Health Phys 109 (4):269-276

[5] Misdaq MA, Elouardi B, Ouguidi J (2017) ^{222}Rn, ^{220}Rn and their progenies measured in the air of different dwellings and workplaces and resulting alpha radiation doses to the eyes of individuals. Health Phys 113:363-374

[6] Kant K, Gupta R, Kumari R, Gupta N, Garg M (2015) Natural radioactivity in Indian vegetation samples. Inter J Radiat Res 13:143-150

[7] International Commission on Radiological Protection (ICRP) (2009) Adult reference computational phantoms. ICRP Publication 110, Ann. ICRP 39, No 2

[8] International Commission on Radiological Protection (ICRP) (2010) The 2010 Recommendations of the International Commission on Radiological Protection. ICRP Publication 116, Ann. ICRP 40, Nos 2-5

[9] Misdaq MA, Khajmi H, Aitnouh F, Berrazzouk S, Bourzik W (2000) A new method for evaluating uranium and thorium contents in different natural material samples by calculating the CR-39 and LR-115 type II SSNTD detection efficiencies for the emitted α-particles. Nucl Instr Meth Phys Res B171: 350-359

[10] Ziegler JF, Biersack JP, Ziegler MD (2013) SRIM. The Stopping and Range of Ions in Matter, Version 2013

[11] International Commission on Radiological Protection (ICRP) (2007) The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Ann. ICRP 37, Nos 2-4

[12] Browne E, Dairiki JM, Doebler RE, Shihab-Eldin AA, Jardine LJ, Tuli JK, Buyrn AB. Table of Isotopes. Seventh Edition. Edited by Lederer CM and V.S. Shirley VS. Wiley-Interscience Publication. 1978

[13] Berger MJ, Coursey JS, Zucker MA, Chang J (2005) ESTAR, PSTAR, and ASTAR Computer programs for calculating stopping–power and range tables for electrons, protons, and helium ions. Version 1.2.3. National Institute of Standards and Technology. Gaithersburg, MD. USA. Available at http//physics.nist.gov/xcom (accessed on 24 April 2018).