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Determination of radiation doses to the skin due to ^{238}U and ^{232}Th series for the therapeutic application in the Merzouga sand baths

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Abstract

In this work, we used CR-39 and LR-115 type II solid-state nuclear track detectors to measure ^{238}U, ^{232}Th, ^{222}Rn and ^{220}Rn concentrations in Merzouga sand. The measured concentrations of ^{238}U and ^{232}Th in the studied sand samples vary from (332.59±16.62) mBq·cm^{-3} to (335.54±20.13) mBq·cm^{-3} and (80.43±4.02) mBq·cm^{-3} to (84.75±5.08) mBq·cm^{-3}, respectively. We evaluated the radiation doses to the skin from the application of different sand baths by the patients by using a model based on specific alpha-dose and alpha-particle residual energy concepts. The maximum total equivalent dose to the skin due to the ^{238}U and ^{232}Th series from the cutaneous application of different sand baths by patients was found equal to (148.12±11.85) μSv y^{-1}cm^{-2}

Key words: Solid Nuclear track detectors; sand baths; environmental radioactivity; ^{238}U and ^{232}Th concentrations; radiation dose assessment to skin.

Introduction

Merzouga is a small Moroccan town in the Sahara Desert, near the Algerian border (**Figure 1**). It is well known for its tourist and therapeutic sand baths, especially for rheumatism treatment. However, the clumsy use of these sand baths causes a lot of health problems affecting, a priori, the human skin layers.

Skin is the largest and heaviest organ in the human body with regard to its surface and mass [1]. It is composed of a series of layers that can be grouped into two structures: the outermost layers are collectively called the epidermis and the deeper layer, the dermis. The critical cells of the skin are found in the basal layer of the epidermis which is the most sensitive skin layer from radiation hazard. Radionuclides have existed since the creation of the earth and contribute significantly to the external and internal doses received by the population [2]. Among them, radionuclides belonging to the ^{238}U and ^{232}Th series are particularly important. These radionuclides emit alpha and beta particles, as well as gamma photons. The different radiation forms are emitted with different energies and power of penetration and therefore have different effects on living beings. Once on the skin, the radionuclides of the ^{238}U and ^{232}Th series emit alpha particles of several tens of microns (between 20 and 100 μm). This is comparable to the depth of the basal layer of the epidermis. It is, therefore, necessary to measure the concentrations of these radionuclides in the studied sand samples, in order to evaluate potential radiation doses and, if appropriate, to take measures to reduce radiation exposure to patients. Eatough et al. used a new engraved track detector, worn as a modified wristwatch, to measure the total alpha activity of the skin at low radon concentrations [3]. Eatough estimated that, for nuclides attached to the skin surface, the doses received by the basal layer are approximately 0.5 and 1 μSv decay^{-1} cm^{-2} for ^{218}Po and ^{214}Po radon decay products, respectively [4].

Figure 1. Merzouga location

To measure the concentrations of ^{238}U, ^{232}Th, ^{222}Rn and thoron, we used a model based on the use of solid-state nuclear track detectors (SSNTDs) described by Misdaq et al. [5]. During the full course of sand bath application to the skin, the equivalent doses to the skin were evaluated due to alpha- particles emitted by the nuclei of ^{238}U and ^{232}Th series.

Materials and Methods

^{238}U and ^{232}Th contents in different sand samples

The principle of the method is that described by Misdaq et al. and Touti [5-7]. In a well-sealed plastic capsule (using glue and cellophane tape), 4 cm in diameter and 1 cm in height, the studied sample is placed in direct contact with the CR-39 and LR-115 type II detectors (**Figure 2**) for one month (30 days). During this exposure time, the alpha particles emitted by radionuclides from the radioactive families of uranium-238 and thorium-232 bombard the used detectors. After this irradiation, the exposed films were developed in two solutions of sodium hydroxide (NaOH) under development optimal conditions ensuring good film sensitivity and good reproducibility of recorded trace densities: 2.5N at 60°C for 2h for the LR-115 type II and 6.25N at 70°C for 7h for the CR-39 [5]. After this chemical treatment, the track densities registered on solid-state nuclear track detectors (CR-39 and LR-115 II) were determined using an optical microscope. Background noise was determined by placing these detectors separately in well-closed and empty (air) polyester cylindrical capsules identical to those used to analyze the sand samples for one month (30 days). This operation is repeated ten times, the trace densities recorded on the detectors CR-39 and LR-115 II were found identical to the statistical uncertainties near.

In our experimental development conditions, the residual thickness of the LR-115 type II detector measured with a mechanical comparator is 5 μm. This thickness defines the minimum energy limit (E_{min} = 1.6 MeV) and the maximum energy limit (E_{max} = 4.7 MeV) for recording traces of alpha particles on the LR-115 type II detector [8].

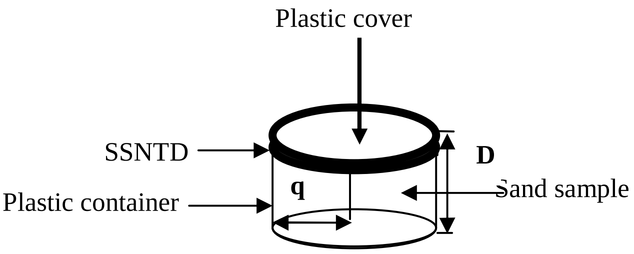

Figure 2. Arrangement of the CR-39 and LR-115 type II solid-state nuclear track detectors (SSNTDs) on a sand sample in a well-closed plastic container of radius q = 2 cm, depth D = 1 cm and thickness t = 5 mm. Glue is put between the plastic cover and plastic container and both are covered by a Sellotape of thickness.

All alpha particles emitted by the radionuclides of uranium-238 and thorium-232 radioactive families reaching the LR-115 Type II detector at an angle below its critical development angle θ'_C with the residual energy of 1.6 MeV and 4.7 MeV are recorded as visible traces under the microscope. The CR-39 is sensitive to all alpha particles that reach its surface at an angle less than its critical development angle θ_C. The angles θ_C and θ'_C were calculated using a method described by Misdaq et al. [9]. The track densities registered on the detectors CR-39 (ρ_G^{CR}) and LR-115 II (ρ_G^{LR}), after subtracting the corresponding backgrounds, are given by the following expressions [5]:

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

Eq. 1

and

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

Eq. 2

where S_d and S_d' are, respectively, the swept surfaces of the CR-39 and LR-115 II films, C(U) (ppm) and C(Th) (ppm) are the ^{238}U and ^{232}Th concentrations in the studied material sample, A_U (Bq/g) = 0.0123 and A_{Th} (Bq/g)=0.0041 are the specific activities of a material sample for a ^{238}U content of 1 ppm and a ^{232}Th content of 1 ppm , respectively. d_S is the density of the material sample (g.cm^{-3}), R_j and R_j' are the ranges in the sample of an alpha particle of index j and initial energy E_j emitted by the nuclei of the ^{238}U and ^{232}Th series respectively, k_j and k_j' are, respectively, the branching ratios corresponding to the disintegration of the nuclei of the ^{238}U, and ^{232}Th series and ε_j^{CR}, $\varepsilon_j^{CR\prime}$, $\varepsilon_j^{LR}$and $\varepsilon_j^{LR\prime}$are, respectively, the detection efficiencies of the CR-39 and LR-115 II detectors for the emitted alpha-particles. The first term (**Equations 1** and **2**) corresponds to the number of alpha-particles emitted by the ^{238}U family (eight alpha-emitting nuclei), whereas the second term corresponds to the number of alpha-particles emitted by the ^{232}Th series (seven alpha-emitting nuclei).

Combining **Equations 1** and **2**, the following relationship between track density rates and ^{232}Th to ^{238}U ratios is obtained:

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

Eq. 3

The uranium content of a material sample is given by (**Equation 4**):

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

Eq. 4

By measuring the global track density rates (ρ_G^{CR}) and (ρ_G^{LR}) and calculating the detection efficiencies (ε_j) and (ε'_j) using the Fortran program "SSNTDE & M" [7], we can evaluate the ratio ($C(Th)/C(U)$) and consequently the uranium and thorium concentrations in a given sand sample (**Equation 4**).

The ranges of the emitted alpha-particles in a sand sample and SSNTDs were calculated by using the TRIM (Transport of Ions in Materials) program [8]. The TRIM code is a FORTRAN computer program based on the theory of penetration of ions in solid as described in detail by Ziegler et al. [10].

Evaluation of the equivalent doses to the skin due to alpha-particles emitted by the nuclei of the ^{238}U and ^{232}Th series from the cutaneous application of sand baths

The epidermis of the human skin is divided into several clearly defined zones [11]. Indeed, when a sand layer is placed on the skin of a patient, the nuclei of the ^{238}U and ^{232}Th series emit alpha-particles with a range of several tens of microns (20 to 100 µm) (**Table 1**). This is comparable with the depth of the basal layer of the epidermis which is more sensitive (50 to 100 µm) [12].

An alpha-particle of index j and initial energy $E_{\alpha j}$ emitted from a nucleus localized on the point M inside the sand layer (**Figure 3**) has a range:

$$\overline{MF} = x_j + R_j^{Skin} \qquad \text{Eq. 5}$$

where x_j ($x_j \leq R_j$, x_j is the range of the alpha-particle inside the sand sample layer) is the distance between the emission point and the skin surface (**Figure 4**) and R_j^{Skin} is the range of the alpha-particle in the skin.

The alpha-particle residual energy $E_{\alpha j}^{Res}$ which corresponds to the (R_j-x_j) determined by using the energy-range relation in the sand sample (**Figure 4a**). By using the energy–range relation in skin one can determine the range of the alpha-particle in skin R_j^{Skin} (**Figure 4b**). For $x_j = R_j$, $E_{\alpha j}^{Res}$=0 MeV; there is no energy loss of alpha-particles in the skin (case 1 of **Figure 3**). For x_j=0 µm, $E_{\alpha j}^{Res} = E_{\alpha j}$; the energy loss of alpha-particles in the skin is maximum (R_j^{Skin} maximum) (case 3 of **Figure 3**). For x_j<R_j, $E_{\alpha j}^{Res}$< $E_{\alpha j}$; the range of alpha-particle in skin is lower than that corresponding to x_j = 0 µm (case 2 of **Figure 3**).

Table 1. Ranges of alpha-particles emitted by the ^{238}U and ^{232}Th series inside the skin R_j^{Skin}

Nuclide	$E_{\alpha j}$ (Mev)	K_j	R_j (µm)	Nuclide	$E_{\alpha j'}$ (Mev)	$K_{j'}$	$R_{j'}$ (µm)
(a) Uranium family				(b) Thorium family			
^{238}**U**	4,19	1	25,64	^{232}**Th**	4,01	1	24,09
^{230}**Th**	4,62	1	29,52	^{228}**Th**	5,42	1	37,40
^{234}**U**	4,77	1	30,94	^{224}**Ra**	5,71	1	40,46
^{226}**Ra**	4,78	1	31,03	^{212}**Bi**	6,05	0,36	44,20
^{210}**Po**	5,30	1	36,16	^{220}**Rn**	6,29	1	46,93
^{222}**Rn**	5,49	1	38,13	^{216}**Po**	6,78	1	52,73
^{218}**Po**	6,00	1	43,64	^{221}**Po**	8,78	0,64	79,62
^{214}**Po**	7,68	1	64,20	-	-	-	-

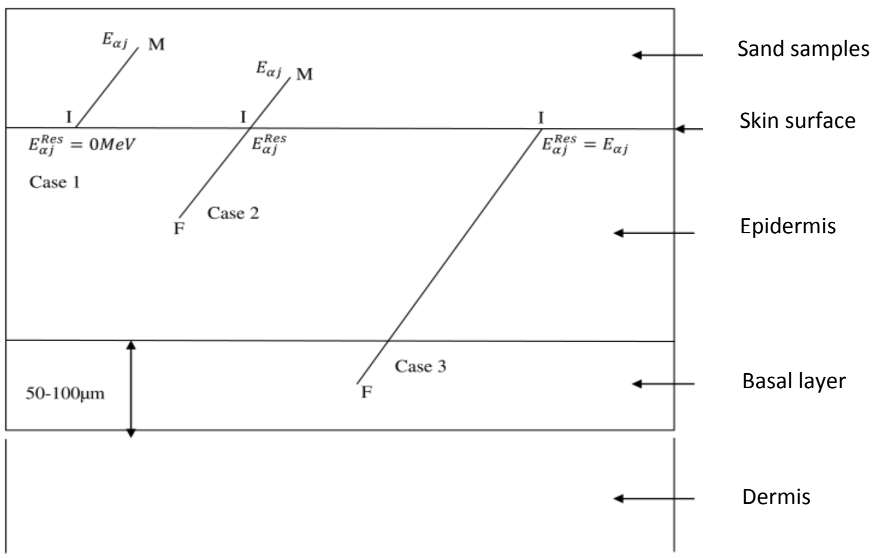

Figure 3. $\overline{MI} = x_j$ **is a range of an alpha-particle inside the sand sample and** $\overline{IF} = R_j^{Skin}$ **is a range of an alpha-particle inside the skin.** $E_{\alpha j}$ **is the initial alpha-particle energy and** $E_{\alpha j}^{Res}$ **is its residual energy on the point I. The sand layer has a depth of about 500 µm.**

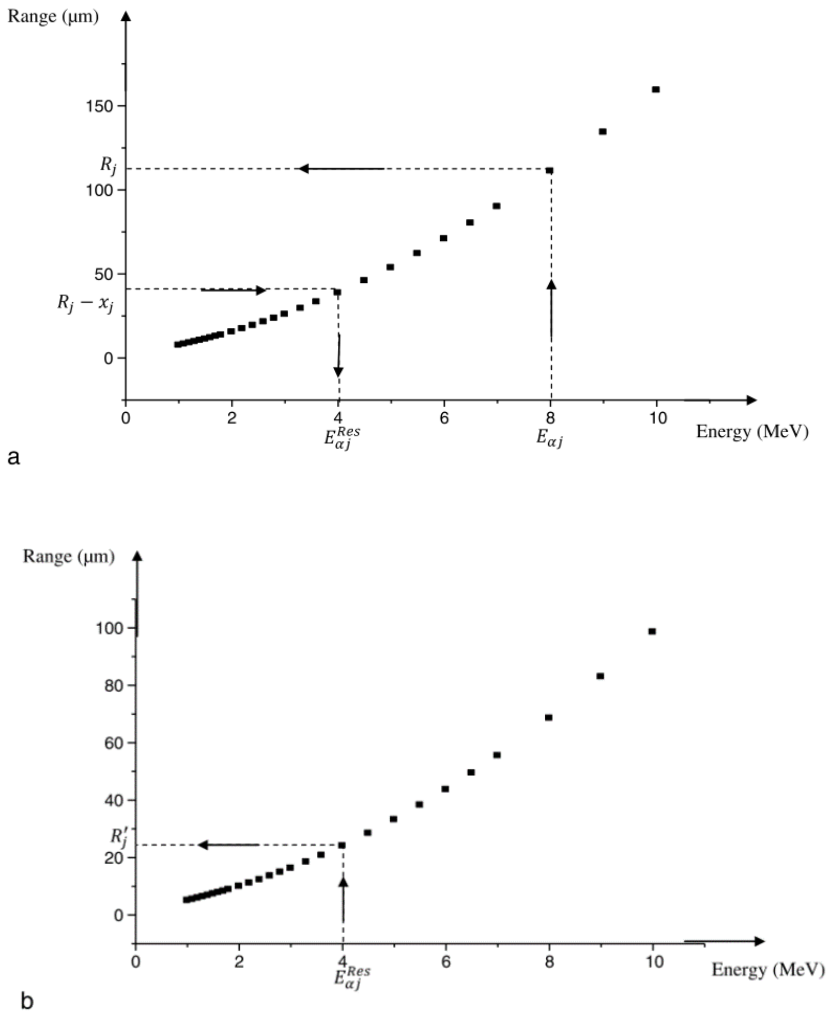

Figure 4. Alpha particle range-energy relation for a sand sample (a) and skin (b).

Alpha-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 from the application of sand bath by patients are respectively given by:

$$\dot{H}_{\text{skin}(j)}(t) = A_{C\ (j)}^{\text{skin}}(t) D_{\text{sp}\ (j)}^{\text{skin}} W_R \quad \text{Eq. 6}$$

and

$$\dot{H}_{\text{skin}(j')}(t) = A_{C\ (j')}^{\text{skin}}(t) D_{\text{sp}\ (j')}^{\text{skin}} W_R \quad \text{Eq. 7}$$

where: $A_{C\ (j)}^{\text{skin}}(t)$ (Bq) is the alpha-activity, at time t, in skin due to a radionuclide of index j belonging to the ^{238}U series. $A_{C\ (j')}^{\text{skin}}(t)$ (Bq) is the alpha-activity, at time t, in skin due to a radionuclide of index j' belonging to the ^{232}Th series. $D_{\text{sp}\ (j)}^{\text{skin}}$ is the specific alpha-dose (Gy) deposited by 1Bq of a radionuclide of index j belonging to the ^{238}U series in the skin. $D_{\text{sp}\ (j')}^{\text{skin}}$ is the specific alpha-dose (Gy) deposited by 1Bq of a radionuclide of index j' belonging to the ^{232}Th series in the skin. W_R is the radiation weighting factor which is equal to 20 for alpha-particles [10].

The $A_{C\ (j)}^{\text{skin}}(t)$ and $A_{C\ (j')}^{\text{skin}}(t)$ alpha-activities are respectively given by:

$$A_{C\ (j)}^{\text{skin}}(t) = \frac{1}{2} A_C^{Sample}(^{238}U) e^{-\lambda_j t} x1cm^3 \quad \text{Eq. 8}$$

and

$$A_{C\ (j')}^{\text{skin}}(t) = \frac{1}{2} A_C^{Sample}(^{232}Th) e^{-\lambda_{j'} t} x1cm^3 \quad \text{Eq. 9}$$

where $A_C^{Sample}(^{238}U)$ (Bq cm^{-3}) is the alpha-activity due to ^{238}U inside a sand sample. $A_C^{Sample}(^{232}Th)$ (Bq cm^{-3}) is the alpha-activity due to ^{232}Th inside a sand 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 means that only half of the emitted alpha-particles inside a sand sample may lose their energies inside the skin.

The $D_{\text{sp}\ (j)}^{\text{skin}}$ and $D_{\text{sp}\ (j')}^{\text{skin}}$ specific alpha-doses are respectively given by:

$$D_{\text{sp}\ (j)}^{\text{skin}} = k \frac{k_j}{d_{Skin} S_{Skin}} \frac{E_{\alpha j}^{Res}}{R_j^{Skin}} \quad \text{Eq. 10}$$

and

$$D_{sp\ (j')}^{skin} = k \frac{k_{j'}}{d_{Skin} S_{Skin}} \frac{E_{\alpha j'}^{Res}}{R_{j'}^{Skin}} \quad \text{Eq. 11}$$

where: d_s 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_j^{skin} is the range, in the skin, of the alpha-particle of index j and residual energy $E_{\alpha j}^{Res}$ belonging to the ^{238}U series. $R_{j'}^{Skin}$ is the range, in the skin, of an alpha-particle of index j' and residual energy $E_{\alpha j'}^{Res}$ belonging to the ^{232}Th series (**Figure 4**).

By integrating **Equations 6** and **7**, equivalent doses (Sv) to the skin due to an alpha-particle of residual energy $E_{\alpha j}^{Res}$ emitted by a radionuclide of index j belonging to the ^{238}U series and an alpha-particle of residual energy$E_{\alpha j'}^{Res}$ emitted by a radionuclide of index j' belonging to the ^{232}Th series from the application of sand baths are respectively given by:

$$H_{Skin(j)} = \frac{D_{sp\ (j)}^{Skin} W_R}{2\lambda_j} A_c^{Sample}(^{238}U)(1 - e^{-\lambda_j t_a}) \quad \text{Eq. 12}$$

and

$$H_{Skin(j')} = \frac{D_{sp\ (j')}^{Skin} W_R}{2\lambda_{j'}} A_c^{Sample}(^{232}Th)(1 - e^{-\lambda_{j'} t_a}) \quad \text{Eq. 13}$$

where t_a is the application time.

Equivalent doses to the epidermis (EP) of 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:

$$H_{(j)}\,(EP) = \frac{k k_j A_c^{Sample}(^{238}U)(1 - e^{-\lambda_j t_a})}{2\lambda_j S_{Skin} d_{Skin} \Delta E_{\alpha j}^{Res}} \int_0^{E_{\alpha j}} \frac{E_{\alpha j}^{Res}}{R_j^{Skin}(E_{\alpha j}^{Res})} dE_{\alpha j}^{Res} \quad \text{Eq. 14}$$

and

$$H_{(j')}(EP) = \frac{k k_j A_c^{Sample}(^{232}Th)(1 - e^{-\lambda_j t_a})}{2\lambda_{j'} S_{Skin} d_{Skin} \Delta E_{\alpha j'}^{Res}} \int_0^{E_{\alpha j'}} \frac{E_{\alpha j'}^{Res}}{R_{j'}^{Skin}(E_{\alpha j'}^{Res})} dE_{\alpha j'}^{Res} \quad \text{Eq. 15}$$

where $\Delta E_{\alpha j}^{Res}$ and $\Delta E_{\alpha j'}^{Res}$ are the chosen steps.

The equivalent doses (Sv y^{-1} cm^{-2}) to a skin surface of 1cm^2 of the epidermis during an exposure time equal to 1 year due to alpha-particles emitted by the ^{238}U (eight alpha-emitting nuclei) and ^{232}Th (seven alpha-emitting nuclei) series from the application of a sand bath by patients are respectively given by:

$$H\,(U)(EP) = \sum_{j=1}^{8} H_{(j)}(Tot) \quad \text{Eq. 16}$$

and

$$H\,(Th)(EP) = \sum_{j=1}^{7} H_{(j')}(Tot) \quad \text{Eq. 17}$$

Results and Discussion

^{238}U and ^{232}Th alpha activities per unit volume in sand samples

The alpha activities per unit volume ^{238}U [A_c(^{238}U)] and ^{232}Th [A_c(^{232}Th)] were evaluated in various sand samples (**Table 2**).

Since the track detectors used were etched in two NaOH solutions at optimal conditions of etching, ensuring a good sensitivity of the SSNTDs and good reproducibility of the registered track density rates and their backgrounds were determined and subtracted from the measured global track density rates registered on these films determined by means of the same optical microscope with magnification 40x, only the statistical uncertainty on track counting is predominant. The uncertainty on track density production per unit time was determined from the statistical uncertainty on track counting, and then the uncertainty of the measured ^{238}U and ^{232}Th concentrations were determined, which gave values of about 8%. The results presented in **Table 2** show that all studied samples contain more uranium than thorium. These activities vary from (332.59 ± 16.62) mBq·cm^{-3} to (335.54 ± 20.13) mBq·cm^{-3} for uranium and from (80.43 ± 4.02) mBq·cm^{-3} to (84.75 ± 5.08) mBq·cm^{-3} for thorium.

Equivalent doses to the skin due to the radionuclides of the ^{238}U and ^{232}Th series from the application of sand baths in Merzouga town

People who are treated for Rheumatism disease take a sand bath in Merzouga can spend 15 minutes a day for one week, one month, or two months. We evaluated the equivalent doses to the epidermis of the skin due to alpha-emitting nuclei of the ^{238}U [H(U)(EP)] and ^{232}Th [H(Th)(EP)] series from the application of sand baths for different exposure times and for female and male adults using equations 16 and 17, the results obtained data for the equivalent doses to the epidermis of human skin (Sv y^{1}cm^{-2}), due to ^{238}U and ^{232}Th series from the cutaneous application of different sand baths of Merzouga by adult female and male for 15 min a day during one week per year, were shown in **Tables 3** and **4**. We have also shown obtained data for the equivalent doses to the epidermis of skin (Sv y^{-1}cm^{-2}), due to the ^{238}U series and ^{232}Th series from the cutaneous application of different sand baths of Merzouga by adult female and male for 15 min a day during one month per year, in **Table 5** and **Table 6**, respectively. Besides, obtained data for the equivalent doses to the epidermis of skin (Sv y^{-1}cm^{-2}), due to the ^{238}U and ^{232}Th series from the cutaneous application of different sand baths of Merzouga by adult female and male for 15 min a day during two months per year, in **Table 7** and **Table 8**, respectively. It is to be noted that the equivalent doses to the epidermis of the skin by female adults always greater than those received by male adults. This is due to the skin surface of female adults which is lower than that of male adults (S_{skin} = 1.90 10^4 cm^2 for the adult male.

S_{skin} = 1.66 10^4 cm^2 for adult female) [2] and that the equivalent doses to the epidermis of skin are inversely proportional to the skin surface. We also note that the equivalent doses are more important when the exposure time is higher. The statistical relative uncertainty of the equivalent dose is estimated to be about 9%. A maximum total equivalent dose to the skin due to the ^{238}U and ^{232}Th series was found equal to **(0.148±0.011)** mSv $y^{-1}cm^{-2}$, obtained for an adult female who spends 15 minutes each day in the sand bath for two months, which is significantly smaller than the dose limit to the skin for the members of the public (**50** mSv $y^{-1}cm^{-2}$) [2].

Table 2. Data obtained for the ^{238}U and ^{232}Th contents in different sand samples.

Sand samples	ρ_G^{LR} x10^5 (tr cm^{-2} s^{-1})	ρ_G^{CR} x10^5 (tr cm^{-2} s^{-1})	C(^{238}U) (ppm)	C(^{232}Th) (ppm)	Ac(^{238}U) (mBq/cm^3)	Ac(^{232}Th) (mBq/cm^3)
S1	56.5±2.82	218.40±10.92	16.92±0.84	12.62±0.63	332.98±16.64	82.79±4.13
S2	57.01±3.42	220.40±13.22	17.05±1.02	12.92±0.77	**335.54±20.13**	**84.75±5.08**
S3	56.90±4.55	219.99±17.59	17.01±1.36	12.80±1.02	334.76±26.78	83.97±6.71
S4	56.20±2.81	217.10±10.85	16.90±0.84	12.26±0.61	**332.59±16.62**	**80.43±4.02**
S5	56.8±3.4	219.60±13.17	16.99±1.01	12.77±0.76	334.36±20.06	83.77±5.02
S6	65.68±4.59	219.10±15.33	16.97±1.18	12.75±0.89	333.97±23.37	83.11±5.81
S7	65.85±5.26	219.75±17.58	17.01±1.36	12.67±1.01	334.75±26.78	83.12±6.64
S8	65.56±3.27	219.03±10.95	17.02±0.85	12.79±0.63	334.96±16.74	83.90±4.19
S9	65.60±3.93	218.75±13.12	16.96±1.01	12.85±0.77	333.77±20.02	84.30±5.05
S10	64.80±4.53	218.76±15.31	16.98±1.18	12.62±0.88	334.16±23.39	82.78±5.79

Table 3. Equivalent doses to the epidermis of skin H(U) (EP) expressed in 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 cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during one week per year

	Sand samples	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^{-8}Sv $y^{-1}cm^{-2}$)	H(^{214}Po) (10^{-15}Sv $y^{-1}cm^{-2}$)	H(U)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	290	322	307	326	356	364	14.52	154	19.76±1.59
	S2	292	325	309	328	359	367	14.63	155	**19.92±1.60**
	S3	291	324	308	327	358	366	14.60	155	19.87±1.59
	S4	289	322	306	325	356	364	14.50	154	**19.74±1.58**
	S5	291	323	308	327	358	366	14.58	155	19.85±1.59
	S6	290	323	308	327	357	365	14.56	155	19.82±1.59
	S7	291	324	308	327	358	366	14.60	155	19.87±1.59
	S8	291	324	309	328	358	366	14.61	155	19.88±1.60
	S9	290	323	308	327	357	365	14.55	155	19.81±1.59
	S10	291	323	308	327	357	365	14.57	155	19.83±1.59
Male	S1	253	281	268	285	311	318	12.69	135	17.27±1.39
	S2	255	284	270	287	314	321	12.78	136	**17.40±1.40**
	S3	254	283	270	286	313	320	12.75	136	17.36±1.39
	S4	253	281	268	284	311	318	12.67	135	**17.25±1.38**
	S5	254	283	269	286	312	319	12.74	135	17.34±1.39
	S6	254	282	269	286	312	319	12.72	135	17.32±1.39
	S7	254	283	270	286	313	320	12.75	136	17.36±1.39
	S8	255	283	270	286	313	320	12.76	136	17.37±1.39
	S9	254	282	269	285	312	319	12.72	135	17.31±1.39
	S10	254	282	269	286	312	319	12.73	135	17.33±1.39

Table 4. Equivalent doses to the epidermis of skin H(Th) (EP) expressed in 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 232Th series from the cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during one week per year

	Sand samples	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^{-8} 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^{-16} Sv $y^{-1}cm^{-2}$)	H(Th)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	278	363	379	77.80	45.32	138.1	2.51	11.01±0.89
	S2	280	366	382	78.40	45.66	139.2	2.53	**11.10±0.89**
	S3	280	365	381	78.22	45.56	138.9	2.53	11.07±0.89
	S4	278	362	378	77.71	45.26	138.0	2.51	**11.00±0.88**
	S5	279	364	380	78.12	45.50	138.7	2.52	11.06±0.89
	S6	279	364	380	78.03	45.45	138.5	2.52	11.04±0.89
	S7	280	365	381	78.21	45.56	138.9	2.53	11.07±0.89
	S8	280	365	381	78.26	45.58	138.9	2.53	11.08±0.89
	S9	279	364	380	77.98	45.42	138.5	2.52	11.04±0.89
	S10	279	364	380	78.08	45.48	138.6	2.52	11.05±0.89
Male	S1	243	317	331	67.97	39.59	120.7	2.20	9.62±0.77
	S2	245	320	334	68.50	39.90	121.6	2.21	**9.70±0.78**
	S3	244	319	333	68.34	39.80	121.3	2.21	9.67±0.78
	S4	243	317	331	67.89	39.55	120.5	2.19	**9.61±0.77**
	S5	244	318	332	68.26	39.76	121.2	2.21	9.66±0.78
	S6	244	318	332	68.18	39.71	121.0	2.20	9.65±0.78
	S7	244	319	333	68.33	39.80	121.3	2.21	9.67±0.78
	S8	245	319	333	68.38	39.83	121.4	2.21	9.68±0.78
	S9	244	318	332	68.13	39.69	121.0	2.20	9.64±0.78
	S10	244	318	332	68.21	39.73	121.1	2.20	9.66±0.78

Table 5. Equivalent doses to the epidermis of skin H(U) (EP) expressed in 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 cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during one month per year

	Sand samples	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^{-8}Sv $y^{-1}cm^{-2}$)	H(^{214}Po) (10^{-15}Sv $y^{-1}cm^{-2}$)	H(U)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	1085	1190	1226	1221	1333	1336	14.52	154	74.03±5.93
	S2	1093	1199	1235	1230	1343	1346	14.63	155	**74.60±5.97**
	S3	1090	1197	1232	1227	1340	1343	14.60	155	74.42±5.96
	S4	1083	1189	1224	1219	1332	1334	14.50	154	**73.94±5.92**
	S5	1089	1195	1231	1226	1339	1342	14.58	155	74.33±5.95
	S6	1088	1194	1229	1224	1337	1340	14.56	155	74.25±5.94
	S7	1090	1197	1232	1227	1340	1343	14.60	155	74.42±5.96
	S8	1091	1197	1233	1228	1341	1344	14.61	155	74.47±5.96
	S9	1087	1193	1229	1224	1336	1339	14.55	155	74.20±5.94
	S10	1089	1195	1230	1225	1338	1341	14.57	155	74.29±5.95
Male	S1	948	1040	1071	1067	1165	1167	12.69	135	64.68±5.18
	S2	955	1048	1079	1075	1174	1176	12.78	136	**65.17±5.22**
	S3	953	1046	1077	1072	1171	1174	12.75	136	65.02±5.21
	S4	947	1039	1070	1065	1163	1166	12.67	135	**64.60±5.17**
	S5	952	1044	1075	1071	1170	1172	12.74	135	64.94±5.20
	S6	951	1043	1074	1070	1168	1171	12.72	135	64.87±5.19
	S7	953	1046	1077	1072	1171	1173	12.75	136	65.02±5.21
	S8	953	1046	1077	1073	1172	1174	12.76	136	65.06±5.21
	S9	950	1043	1074	1069	1168	1170	12.72	135	64.83±5.19
	S10	951	1044	1075	1070	1169	1171	12.73	135	64.91±5.20

Table 6. Equivalent doses to the epidermis of skin H(Th) (EP) expressed in 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 cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during one month per year

	Sand samples	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^{-8} 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^{-16} Sv $y^{-1}cm^{-2}$)	H(Th)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	1042	1359	1419	103.74	45.32	138.1	2.51	39.27±3.15
	S2	1050	1370	1430	104.53	45.66	139.2	2.53	**39.58±3.17**
	S3	1047	1366	1427	104.29	45.56	138.9	2.53	39.48±3.16
	S4	1040	1358	1418	103.62	45.26	138.0	2.51	**39.23±3.14**
	S5	1046	1365	1425	104.17	45.50	138.7	2.52	39.44±3.16
	S6	1045	1363	1424	104.05	45.45	138.5	2.52	39.39±3.16
	S7	1047	1366	1427	104.29	45.56	138.9	2.53	39.48±3.16
	S8	1048	1367	1428	104.35	45.58	138.9	2.53	39.51±3.17
	S9	1044	1362	1423	103.98	45.42	138.5	2.52	39.37±3.15
	S10	1045	1364	1424	104.10	45.48	138.6	2.52	39.41±3.16
Male	S1	910	1188	1240	90.63	39.59	120.7	2.20	34.31±2.75
	S2	917	1197	1250	91.33	39.90	121.6	2.21	**34.58±2.77**
	S3	915	1194	1247	91.12	39.80	121.3	2.21	34.50±2.76
	S4	909	1186	1239	90.53	39.55	120.5	2.19	**34.27±2.75**
	S5	914	1192	1245	91.01	39.76	121.2	2.21	34.46±2.76
	S6	913	1191	1244	90.90	39.71	121.0	2.20	34.42±2.76
	S7	915	1194	1247	91.12	39.80	121.3	2.21	34.50±2.76
	S8	916	1195	1248	91.17	39.83	121.4	2.21	34.52±2.77
	S9	912	1190	1243	90.85	39.69	121	2.20	34.40±2.76
	S10	913	1192	1245	90.96	39.73	121.1	2.20	34.44±2.76

Table 7. Equivalent doses to the epidermis of skin H(U) (EP) expressed in 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 cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during two month per year

	Sand samples	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^{-8}Sv $y^{-1}cm^{-2}$)	H(^{214}Po) (10^{-15}Sv $y^{-1}cm^{-2}$)	H(U)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	2169	2364	2451	2440	2664	2598	14.52	154	146.99±11.76
	S2	2186	2382	2470	2459	2685	2618	14.63	155	**148.12±11.85**
	S3	2180	2377	2464	2454	2679	2612	14.60	155	147.78±11.83
	S4	2166	2361	2448	2438	2661	2595	14.50	154	**146.82±11.75**
	S5	2178	2374	2461	2451	2675	2609	14.58	155	147.60±11.81
	S6	2175	2371	2458	2448	2672	2606	14.56	155	147.43±11.80
	S7	2180	2377	2464	2453	2678	2612	14.60	155	147.77±11.83
	S8	2182	2378	2466	2455	2680	2614	14.61	155	147.86±11.83
	S9	2174	2370	2457	2446	2671	2604	14.55	155	147.34±11.79
	S10	2177	2372	2460	2449	2674	2607	14.57	155	147.51±11.81
Male	S1	1895	2066	2141	2132	2328	2270	12.69	135	128.42±10.28
	S2	1910	2081	2158	2149	2346	2287	12.78	136	**129.41±10.36**
	S3	1905	2077	2153	2144	2340	2282	12.75	136	129.11±10.33
	S4	1893	2063	2139	2130	2325	2267	12.67	135	**128.27±10.27**
	S5	1903	2074	2150	2141	2337	2279	12.74	135	128.96±10.32
	S6	1901	2072	2148	2139	2335	2277	12.72	135	128.80±10.31
	S7	1905	2077	2153	2144	2340	2282	12.75	136	129.11±10.33
	S8	1906	2078	2154	2145	2342	2284	12.76	136	129.19±10.34
	S9	1899	2070	2147	2137	2333	2275	12.72	135	128.73±10.30
	S10	1902	2073	2149	2140	2336	2278	12.73	135	128.88±10.32

Table 8. Equivalent doses to the epidermis of skin H(Th) (EP) expressed in 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 cutaneous application of different sand baths of Merzouga by an adult female for 15 min a day during two months per year

	Sand samples	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^{-8} 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^{-16} Sv $y^{-1}cm^{-2}$)	H(Th)(EP) (μSv $y^{-1}cm^{-2}$)
Female	S1	2083	2717	2838	104.35	45.32	138.1	2.51	77.46±6.20
	S2	2099	2738	2860	105.15	45.66	139.2	2.53	**78.06±6.25**
	S3	2094	2732	2853	104.91	45.56	138.9	2.53	77.88±6.24
	S4	2080	2714	2835	104.23	45.26	138.0	2.51	**77.37±6.19**
	S5	2091	2729	2850	104.78	45.50	138.7	2.52	77.78±6.23
	S6	2089	2725	2847	104.66	45.45	138.5	2.52	77.69±6.22
	S7	2094	2732	2853	104.90	45.56	138.9	2.53	77.87±6.23
	S8	2095	2734	2855	104.97	45.58	138.9	2.53	77.92±6.24
	S9	2088	2724	2845	104.60	45.42	138.5	2.52	77.65±6.22
	S10	2090	2727	2848	104.72	45.48	138.6	2.52	77.74±6.22
Male	S1	1820	2374	2480	91.17	39.59	120.7	2.20	67.68±5.42
	S2	1834	2392	2499	91.87	39.90	121.6	2.21	**68.20±5.46**
	S3	1829	2387	2493	91.66	39.80	121.3	2.21	68.04±5.45
	S4	1818	2371	2477	91.06	39.55	120.5	2.19	**67.60±5.41**
	S5	1827	2384	2490	91.55	39.76	121.2	2.21	67.96±5.44
	S6	1825	2381	2487	91.44	39.71	121.0	2.20	67.88±5.44
	S7	1829	2387	2493	91.65	39.80	121.3	2.21	68.04±5.45
	S8	1831	2388	2495	91.71	39.83	121.4	2.21	68.08±5.45
	S9	1824	2380	2486	91.39	39.69	121.0	2.20	67.84±5.43
	S10	1826	2383	2489	91.49	39.73	121.1	2.20	67.92±5.44

Conclusion

In this work, it has been shown that the use of CR-39 and LR-115 type II solid-state nuclear track detectors (SSNTDs) allows evaluation of ^{238}U and ^{232}Th alpha activities per unit volume in various sand samples. This method used has the advantage of being inexpensive, accurate, and sensitive and does not need the use of standard sources for its calibration. It is a useful tool for measuring ^{238}U and ^{232}Th concentrations in a sand material sample. A personalized dosimetric model has been developed in order to assess radiation doses to the skin due to the alpha-emitting nuclei of the ^{238}U and ^{232}Th series from the application of sand baths. It is concluded that equivalent doses to the skin due to the alpha-emitting nuclei of the ^{238}U and ^{232}Th series increase with the application time of the studied materials. One can conclude that there is no radiation hazard to the sensitive basal layer of the epidermis from the application of sand baths by the patients. Nevertheless, we can take into account the stochastic effects which do not have a threshold dose and can appear at low doses. For this reason, we recommend people having undergone a rheumatism treatment to reduce as low as possible their spent time in sand baths.

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