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# $^{222}$Rn and $^{220}$Rn concentrations measured in bottled sweet drinks and their residual gases and resulting radiation doses to the consumers

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**Abstract:** Presently bottled sweet drinks are widely consumed by different age groups of individuals all over the world. Since bottling until consumption of sweet drinks, residual gas containing $^{222}$Rn and $^{220}$Rn isotopes is formed. To assessradiation dose to the consumers from the ingestion of sweet drinks, $^{222}$Rn and $^{220}$Rn concentrations were measured in different sweet drinks and their residual gases by using CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs). The measured $^{222}$Rn and $^{220}$Rn concentrations ranged from (0.350±0.028) Bql$^{-1}$ to (4.25±0.29) Bql$^{-1}$ and (0.140±0.008) Bql$^{-1}$ to (4.25±0.38) Bql$^{-1}$, respectively. α-activities due to the annual intake of $^{222}$Rn were assessed in the tissues and organs of the gastrointestinal tract of the considered consumers. Committed effective doses due to the ingestion of $^{222}$Rn contained in each sweet drink and its corresponding residual gas were evaluated in the gastrointestinal system of adult and teenager members of the Moroccan population. The maximum value of the committed effective dose due to $^{222}$Rn from the ingestion of the studied sweet drinks was found equal to7.9 μSv y$^{-1}$.

**Keywords**: Sweet Drinks, Residual Gases, Nuclear Track Detectors, Radon, Dose Assessment

## 1. Introduction

Naturally occurring radionuclides enter the human body mainly by inhalation of radon and thorn gases and their decay products [1] and by ingestion of food and water [2-5].

The Moroccan population consumes sweet drinks more and more, especially adults and teenagers. These sweet drinks are made up mainly of water and sugar; therefore they contain primordial radioisotopes ($^{238}$U, $^{232}$Th, $^{40}$K). Radon ($^{222}$Rn) is a chemically inert and very mobile gaseous decay product of $^{238}$U which is found in all rocks and soils as well as water. Inhalation and ingestion of radon and its progeny represent the main source of exposure to ionizing radiation for population in most countries. It is necessary to measure radon content of sweet drink samples to assess potential radiation doses and, if necessary, to take action to avoid the exposure of consumers to radiation. Radon concentrations have been measured in different water samples by using the liquid scintillation method [6-9], which is destructive (chemical agents are added to water) and needs the use of standard solution sources for its calibration. Many authors have evaluated doses to organs and tissues due to radon from the ingestion of water [10, 11]. In the work described here, we used a method based on combining two techniques. The first one consists of calculating the detection efficiencies of the CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) for α-particles emitted by the $^{238}$U and $^{232}$Th radioactive families including those emitted by the $^{222}$Rn and $^{220}$Rn groups and exploiting the corresponding track densities for evaluating $^{222}$Rn and $^{220}$Rn α-activities inside different sweet drink samples. The second technique consists of calculating the stopping powers of the gastrointestinal tissues for α-particles emitted by $^{222}$Rn for evaluating annual effective doses due to radon in the human gastrointestinal tract from the ingestion of sweet drinks.

# 2. Methods of Study

### *2.1. Determination of $^{22}$Rn and $^{220}$Rn Concentrations in Different Sweet Drink Samples and Their Corresponding Residual Gases*

Sweet drink samples were separately placed in close contact with disk shaped CR-39 (manufactured by Per shoreMoldings Ltd., U.K) and LR-115 type II (manufactured by Kodak Pathé, France and marketed by Dosirad, France) solid state nuclear track detectors (SSNTDs) of radius q=2cm in hermetically sealed (using glue and a cellophane tape) cylindrical plastic containers for one month (30 days) (Figure1). During this period of time α-particles emitted by the nuclei of $^{238}$U, $^{232}$Th and their daughters inside the sweet drink samples exposed the SSNTD films. After the irradiation, the exposed SSNTDs were etched in two NaOH solutions: one was of 2.5 normality at 60°C during 2 hours for the LR-115 II films and the other of 6.25 normality at 70°C for 7 hours for the CR-39 detectors [12]. After chemical treatment, the track densities registered on the CR-39 and LR-115 II SSNTDs were determined by means of an ordinary microscope. Backgrounds on the CR-39 and LR-115 II SSNTDs were evaluated by placing these films in sealed plastic containers, containing ambient air, identical to those used for analysing the sweet drink samples for one month and counting the resulting track densities. The mean background track density rates registered on the CR-39 and LR-115 II detectors were found equal to (1.26±0.05) $10^{-6}$ tracks cm$^{-2}$ s$^{-1}$ and (0.62±0.05) $10^{-6}$ tracks cm$^{-2}$ s$^{-1}$, respectively.

There are three main factors which disturb the radioactive secular equilibrium between $^{238}$U and its progeny and between $^{232}$Th and its daughters: (a) the addition of any chemical compounds to the sweet drink sample, (b) any escape of radon and thoron gases and (c) the exposure time if it is smaller than 25 days. As the detection system used was well-sealed (i.e., there was no escape of radon and thoron) and the exposure time was 30 days, a radioactive secular equilibrium is established between $^{238}$U and each of its decay products and between $^{232}$Th and each of its daughters. For the experimental etching conditions, the residual thickness of the LR-115 type II detectors measured by means of a mechanical comparator is 5µm. This thickness defines the lower ($E_{min}$= 1.6MeV) and upper ($E_{max}$ = 4.7MeV) energy limits for registration of tracks of alpha-particles in LR-115 type II films [13]. All α-particles emitted by the $^{238}$U and $^{232}$Th series that reach the LR-115 detector at an angle smaller than its critical angle of etching, $\theta_c^{'}$,with a residual energy between 1.6MeV and 4.7MeV are registered as bright track-holes. The CR-39 detector is sensitive to all alpha-particles reaching its surface at an angle smaller than its critical angle of etching, $\theta_c$. The critical angles of etching $\theta_c^{'}$ and $\theta_c$ were calculated by using the method described in detail by Misdaq et al.[14].

According to one of our previous works [15] when we place the SSNTDs directly on the studied sweet drink samples and since a secular radioactive equilibrium is established between $^{238}$U, $^{232}$Th and their corresponding daughters, track densities due to α-particles emitted by the $^{238}$U and $^{232}$Th series inside these samples and registered on the CR-39 ( $\rho_G^{CR}$ (in)) and LR-115 type II ( $\rho_G^{LR}$ (in)) films are given by:

$$\rho_G^{CR}(in) = \frac{\pi q^2}{2\,S_d}\left[A_c(^{222}Rn)(in)\sum_{j=1}^{8} k_j\,R_j\varepsilon_j^{CR} + A_c(^{220}Rn)(in)\sum_{j=1}^{7} k_j^{'}\,R_j^{'}\varepsilon_j^{'CR}\right] \quad (1)$$

and

$$\rho_G^{LR}(in) = \frac{\pi q^2}{2\,S_d^{'}}\left[A_c(^{222}Rn)(in)\sum_{j=1}^{8} k_j\,R_j\varepsilon_j^{LR} + A_c(^{220}Rn)(in)\sum_{j=1}^{7} k_j^{'}\,R_j^{'}\varepsilon_j^{'LR}\right] \quad (2)$$

where $S_d$ and $S_d^{'}$ are respectively the surface areas of the CR-39 and LR-115 II films, $R_j$ and $R_j^{'}$ are the ranges, in the sample, of an α-particle of index j and initial energy $E_j$ emitted by the nuclei of the uranium and thorium series, respectively, $k_j$ and $k'_j$ are respectively the branching ratios corresponding to disintegration of the nuclei of the uranium and thorium series and $\varepsilon_j^{CR}$ , $\varepsilon_j^{'CR}$ , $\varepsilon_j^{LR}$ and $\varepsilon_j^{'LR}$ are respectively the detection efficiencies of the CR-39 and LR-115 type II detectors for the emitted α-particles. The first terms (right of Equations (1) and (2)) correspond to the number of α-particles emitted by the $^{238}$U family (8α-emitting nuclei), whereas the second terms correspond to the number of α-particles emitted by the $^{232}$Th series (7 ~αemitting nuclei). $A_c(^{222}Rn)(in)$ (Bqcm$^{-3}$) and $A_c(^{220}Rn)(in)$ (Bqcm$^{-3}$) are the $^{222}$Rn and $^{220}$Rnα-activities inside a sweet drink sample, respectively.

Combining Equations (1) and (2), we obtain the following relationship between track density rates and $^{220}$Rn to $^{222}$Rn ratios:

$$\frac{A_c(^{220}Rn)(in)}{A_c(^{222}Rn)(in)} = \frac{\frac{S_d^{'}}{S_d}\sum_{j=1}^{8} k_j\varepsilon_j^{CR}R_j - \frac{\rho_G^{CR}(in)}{\rho_G^{LR}(in)}\sum_{j=1}^{8} k_j\varepsilon_j^{LR}R_j}{\frac{\rho_G^{CR}(in)}{\rho_G^{LR}(in)}\sum_{j=1}^{7} k_j^{'}\varepsilon_j^{'CR}R_j^{'} - \frac{S_d^{'}}{S_d}\sum_{j=1}^{7} k_j^{'}\varepsilon_j^{'LR}R_j^{'}} \quad (3)$$

The $^{222}$Rnα-activity of a sweet drink sample is given from Equation (2):

$$A_c(^{222}Rn)(in) = \frac{2\,S_d^{'}\,\rho_G^{LR}(in)}{\pi q^2 d_s\left[\sum_{j=1}^{8} k_j\varepsilon_j^{LR}R_j + \frac{A_c(^{220}Rn)(in)}{A_c(^{222}Rn)(in)}\sum_{j=1}^{7} k_j^{'}\varepsilon_j^{'LR}R_j^{'}\right]} \quad (4)$$

When placing the SSNTDs at a distance of 9 cm above

the sweet drink sample during 30 days (Figure 2), a secular radioactive equilibrium is established between $^{222}$Rn and its progeny and between $^{220}$Rn and its decay products inside the residual gas and the $^{222}$Rn ($A_c(^{222}Rn)(out)$) and $^{220}$Rn ($(A_c(^{220}Rn)(out)$) α-activities per unit volume outsidethe studied sweet drink sample can be determined, according to a method developed by Misdaq et al. [15], by calculating the detection efficiencies of the CR-39 and LR-115 II nuclear track detectors for α-particles emitted by the $^{222}$Rnand $^{220}$Rn series inside the residual gas(Table 1)[15] and measuring the corresponding track density rates registered on the CR-39 ($\rho_G^{CR}$ (out)) and LR-115 type II ($\rho_G^{LR}$ (out)). The distance of 9 cm above the sweet drink sample has been chosento avoid the bombardment of the SSNTD films by 8.78 MeV α-particles which have a range of 8.36 cm in air (residual gas) and are emitted by the $^{212}$Po nuclei at the surface of the sweet drink sample (Figure 2). These $^{212}$Po nuclei, which are present just at the surface of the sweet drink sample, come from the disintegration of the $^{220}$Rn inside the sweet drink sample. Indeed, we have:

***Table 1.*** *Values of the ranges ($R_j$and$R_j^{'}$) and CR-39 and LR-115 II SSNTDs detection efficiencies for α-particles emitted by the $^{222}$Rn(a) and $^{220}$Rn (b) series in air.*

| Nuclide | | Alpha-particle energy (MeV) | R(cm) | $\varepsilon_j^{CR}$ (%) | $\varepsilon_j^{LR}$ (%) |
|---|---|---|---|---|---|
| Radon group | $^{222}$Rn | 5.49 | 4.03 | 21.83 | 16.96 |
| | $^{218}$Po | 6.00 | 4.62 | 21.93 | 15.08 |
| | $^{214}$Po | 7.68 | 6.83 | 22.17 | 10.67 |

| Nuclide | | Alpha-particleenergy (MeV) | $R_j^{'}$(cm) | $\varepsilon_j^{CR}$ (%) | $\varepsilon_j^{LR}$ (%) |
|---|---|---|---|---|---|
| Thoron group | $^{220}$Rn | 6.29 | 4.98 | 21.98 | 14.32 |
| | $^{216}$Po | 6.78 | 5.60 | 22.07 | 12.82 |
| | $^{212}$Bi | 6.05 | 4.68 | 21.93 | 14.92 |
| | $^{212}$Po | 8.78 | 8.48 | 22.27 | 8.72 |

$$\frac{\rho_G^{CR}(out)}{\rho_G^{LR}(out)} = \frac{S_d^{'}}{S_d} \times \frac{\sum_{j=1}^{3} k_j R_j \varepsilon_j + \frac{A_c(^{220}Rn)(out)}{A_c(^{222}Rn)(out)} \sum_{j=1}^{4} k_j R_j \varepsilon_j}{\sum_{j=1}^{3} k_j R_j \varepsilon_j^{'} \frac{A_c(^{220}Rn)(out)}{A_c(^{222}Rn)(out)} \sum_{j=1}^{4} k_j R_j \varepsilon_j^{'}} \quad (5)$$

and

$$\rho_G^{LR}(out) = \frac{A_c(^{222}Rn)(out)\pi q^2}{2 S_d^{'}} \sum_{j=1}^{3} k_j R_j \varepsilon_j^{'} + \frac{A_c(^{220}Rn)(out)\pi q^2}{2 S_d^{'}} \sum_{j=1}^{4} k_j R_j \varepsilon_j^{'} \quad (6)$$

Measuring the $\rho_G^{CR}$(in), $\rho_G^{LR}$(in), $\rho_G^{CR}$(out) and $\rho_G^{LR}$ (out) track density rates and calculating the $\varepsilon_j^{CR}$, $\varepsilon_j^{'CR}$, $\varepsilon_j^{LR}$ and $\varepsilon_j^{'LR}$ detection efficiencies[15] one can evaluate the $\frac{A_c(^{220}Rn)(in)}{A_c(^{222}Rn)(in)}$ and $\frac{A_c(^{220}Rn)(out)}{A_c(^{222}Rn)(out)}$ ratios and consequently the $A_c(^{222}Rn)(in)$, $A_c(^{220}(Rn)(in)$, $A_c(^{222}Rn)(out)$, and $A_c(^{220}Rn)(out)$ ((Equations(3)-(6))) -activities per unit volume of a given sweet drink sample.

The ranges of the emitted α-particles in sweet drinks and SSNTDs were calculated by using the TRIM (Transport of Ions in Materials) code[16].

### *2.2. Determination of Alpha-Activity Due To $^{222}$Rnin the Human Gastrointestinal Tract from the Ingestion of Various Sweet Drink Samples*

According to the International Commission on Radiological Protection dosimetric model for the gastrointestinal system[17] each of the four sections of this system consists of a single compartment: the stomach (St), small intestine (Si), upper large intestine (Uli) and lower large intestine (Lli). There are two pathways out of the Si: one leads to the Uli and the other to blood (B) as shown in Figure 3.

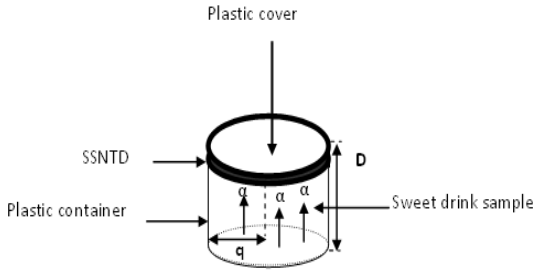


***Figure 1.*** *Arrangement of the solid state nuclear track detectors (SSNTDs) on a beauty cream material sample in a well-sealed plastic container of radius q= 2cm, depth D= 1cm and thickness t= 5mm. Glue is put between the plastic cover and plastic container and both are covered by a cellophane tape of 2 mm thickness.*

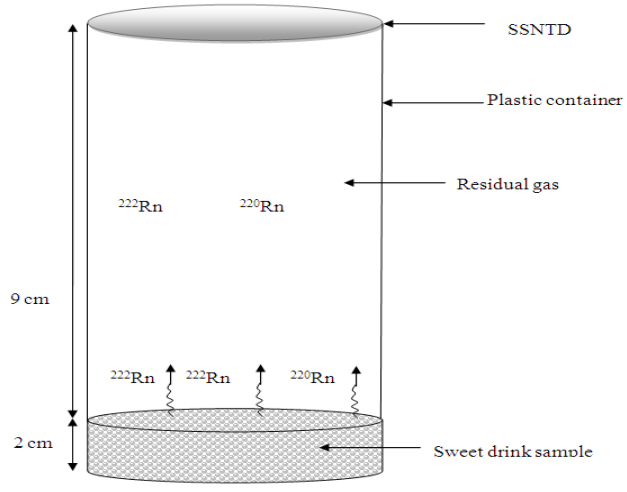


***Figure 2.*** *Arrangement of the solid state nuclear track detector films*

*placed at a distance of 9 cm above a sweet drink sample in a hermetically sealed cylindrical plastic container of radius q= 2cm, depth D= 11cm 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.*

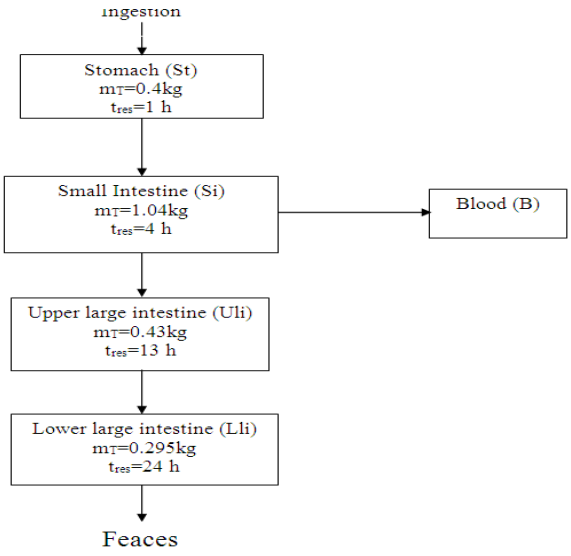


***Figure 3.****Compartmental dosimetric model for the gastrointestinal system [17].$m_T$ is the mass tissue [18]. $t_{res}$ is the mean residence time of radon in organs [17].*

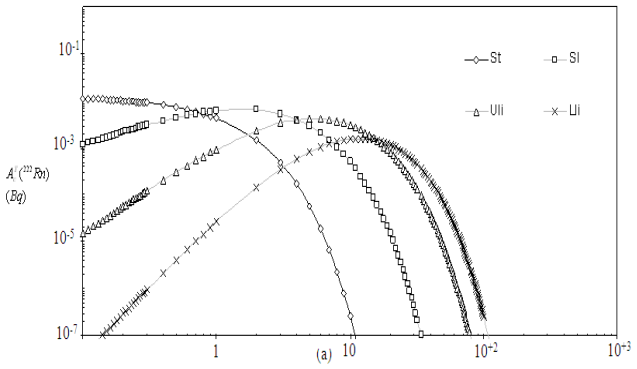


***Figure 4.****Variation of the alpha- activity of $^{222}$Rn as a function of time in the gastrointestinal compartments from the ingestion of sweet drink by the members of the AG7 group of consumers during 1 y.*

$^{222}$Rn is soluble in water (sweet drink)[19]. After the ingestion of sweet drinks by individuals, $^{222}$Rn is transferred from the stomach to the other organs of the gastrointestinal system[10]. α-activities due to $^{222}$Rn in the different tissues of the gastrointestinal system from the ingestion of various sweet drink samples by individuals are obtained by solving the differential equation system representing the rates of change of these activities by using a Maple 8 code[20] providing that at t=0 these activities are equal to zero except that in the stomach. Assuming that all the ingested radon from sweet drink appears in the stomach, the radon α-activity in a tissue T of the gastrointestinal tract is given by[3]:

$$A_c^T(^{222}Rn)(t) = I(^{222}Rn)\sum_{i=1}^{4} a_i^T e^{-b_i^T t} \qquad (7)$$

where$I(^{222}Rn)$ (in Bq $y^{-1}$) is the radon intake from the ingestion of a sweet drink sample, $a_i^T$ is a constant and $b_i^T$ is a rate constant expressed in $h^{-1}$.

### *2.3. Evaluation of Annual Committed Equivalent Doses Due To $^{222}$Rn in the Human Gastrointestinal Tract from the Ingestion of Sweet Drinks and Their Corresponding Residual Gases*

Assuming that only 1% of the energy of the α-particles is included in computing the effective energies for the GI tract [21], the α-equivalent dose rate (Sv $s^{-1}$) in a tissue T of the human gastrointestinal system due to $^{222}$Rn from the ingestion of a sweet drink sample by individuals is given by:

$$H_T(^{222}Rn)(t) = 10^{-2}\, D_{sp}^{T}(^{222}Rn)\,.A_c^T(^{222}Rn)(t).W_R \qquad (8)$$

where $A_c^T(^{222}Rn)$ is the α-activity due to $^{222}$Rn in the tissue T of the gastrointestinal system, $D_{sp}^T(^{222}Rn)$ is the specific α-dose (Gy) deposited by α-particles emitted by 1Bq of $^{222}$Rn in the tissue T and $W_R$ is the radiation weighting factor which is equal to 20 for α-particles[22].

The $D_{sp}^T(^{222}Rn)$ specific α-dose is given by:

$$D_{sp}^T(^{222}Rn) = k.\frac{K_j R_j S_j}{m_T} \qquad (9)$$

where$m_T$ is the mass of the target tissue T,$K_j$ is the branching ratio for $^{222}$Rn disintegration. $R_j$ is the range of the α-particle emitted by $^{222}$Rn,$S_j$ is the stopping power of the tissue T for the α-particle emitted by $^{222}$Rn, and $k=1.6\times10^{-13}$ (J $MeV^{-1}$) is a conversion factor.

The committed equivalent dose due to $^{222}$Rn in the tissue T from the ingestion of a sweet drink sample is given by:

$$H_T(^{222}Rn) = 10^{-2}\, W_R k \frac{K_j R_j S_j}{m_T}\int_0^{te} A_c^T(^{222}Rn)(t)dt \qquad (10)$$

where$t_e$ is the exposure time.

The committed effective dose due to $^{222}$Rn from the ingestion of a sweet drink sample is given by:

$$E_{Rn} = \sum W_T H_T(^{222}Rn) \qquad (11)$$

where $W_T$ is the tissue weighting factor[22].

## 3. Results and Discussion

### *3.1. $^{222}$Rnand $^{220}$RnIntakes from the Ingestion of Sweet Drinks and Their Corresponding Residual Gases*

Various bottled sweet drinks widely consumed by adult and teenager members of the Moroccan population have been collected and analyzed. $^{222}$Rn and $^{220}$Rn

concentrations have been measured inside ($A_c(^{222}Rn)(in)$ and $A_c(^{220}Rn)(in)$) (Equations (3) and (4)) and outside ($A_c(^{222}Rn)(out)$ and $A_c(^{222}Rn)(out)$) (Equations (5) and (6)) the studied sweet drink samples. Data obtained are shown in Table 2.From the statistical uncertainty on track counting one can determine the uncertainty on track density production per unit time and then evaluate the uncertainty of the $^{222}Rn$ and $^{220}Rn$ concentrations determination which is about 8%.It is to be noted from results shown in Table 2 that the SD3, SD5, SD6, SD8, SD9, SD10, SD11, SD14, SD15, SD17, and SD18 sweet drink samples contain more $^{222}Rn$ than $^{220}Rn$. This is because these samples contain more $^{238}U$ than $^{232}Th$. It is also noted that the SD1, SD2, SD4, SD7, SD12, SD13, SD16 sweet drink samples show higher $^{220}Rn$ concentration than that of $^{222}Rn$. This due to the fact that these samples contain more $^{232}Th$ than $^{238}U$.It is to be noted that $^{222}Rn$ α-activity per unit volume is higher than that of $^{220}Rn$ outside all the sweet drink samples studied. This is because $^{220}Rn$ has a shorter half-life (55s) than $^{222}Rn$ (3.82 d). The global $^{222}Rn$ α-activity per unit volume ($A_c(^{222}Rn)(in)$ plus $A_c(^{222}Rn)(out)$) ranged between (0.37±0.03) and (4.7±0.3) kBq $m^{-3}$ (Table 2).

***Table 2.*** *Data obtained for the $^{222}Rn$ α-activity per unit volume and $^{220}Rn$ α-activity per unit volume inside ($A_c(^{222}Rn)(in)$ and $A_c(^{220}Rn)(in)$) and outside ($A_c(^{222}Rn)(out)$ and $A_c(^{220}Rn)(out)$) various sweet drink samples.*

| Samples | $\rho_{CR}(in)$ ($10^{-6}$tr $cm^{-2}$ $s^{-1}$) | $\rho_{LR}(in)$ ($10^{-6}$tr $cm^{-2}$ $s^{-1}$) | $A_c(^{222}Rn)(in)$ (kBq/$m^3$) | $A_c(^{220}Rn)(in)$ (kBq/$m^3$) | $\rho_{CR}(out)$ ($10^{-6}$tr $cm^{-2}$ $s^{-1}$) | $\rho_{LR}(out)$ ($10^{-6}$tr $cm^{-2}$ $s^{-1}$) | $A_c(^{222}Rn)(out)$ (Bq/$m^3$) | $A_c(^{220}Rn)(out)$ (Bq/$m^3$) | $A_c(^{222}Rn)(global)$ (kBq/$m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| SD1 | 40.63±3.04 | 9.67±0.75 | 0.35±0.02 | 3.4±0.2 | 7.25±0.20 | 2.60±0.09 | 23±1 | 48±2 | 0.37±0.03 |
| SD2 | 54.13±4.44 | 14.63±1.07 | 2.5±0.1 | 2.7±0.2 | 25.31±1.11 | 11.07±0.42 | 232±9 | 32±1 | 2.7±0.1 |
| SD3 | 50.31±4.06 | 13.97±0.85 | 2.6±0.1 | 2.0±0.1 | 26.54±1.15 | 11.91±0.48 | 251±10 | 29±1 | 2.8±0.1 |
| SD4 | 76.05±5.94 | 20.01±1.56 | 2.7±0.2 | 4.2±0.3 | 31.71±1.25 | 13.15±0.47 | 272±11 | 54±2 | 3.0±0.2 |
| SD5 | 24.95±1.88 | 7.79±0.51 | 2.2±0.1 | 0.14±0.01 | 16.82±0.56 | 7.70±0.32 | 180±6 | 1.00±0.06 | 2.4±0.1 |
| SD6 | 48.68±3.95 | 13.91±0.78 | 3.0±0.2 | 1.54±0.08 | 32.18±1.35 | 12.00±0.50 | 310±13 | 27±1 | 3.3±0.2 |
| SD7 | 42.46±3.25 | 11.47±0.72 | 1.9±0.1 | 2.1±0.1 | 13.07±0.45 | 5.43±0.22 | 108±4 | 26±1 | 2.0±0.1 |
| SD8 | 58.44±3.42 | 17.18±1.15 | 4.0±0.3 | 1.3±0.1 | 39.61±1.50 | 14.18±0.62 | 392±15 | 20.0±0.5 | 4.4±0.3 |
| SD9 | 31.67±2.21 | 9.59±0.72 | 2.5±0.1 | 0.42±0.02 | 20.21±0.75 | 8.45±0.28 | 210±7 | 5.0±0.2 | 2.7±0.1 |
| SD10 | 38.56±3.02 | 12.05±0.71 | 3.4±0.2 | 0.18±0.01 | 26.96±1.05 | 11.76±0.47 | 350±14 | 2.0±0.1 | 3.8±0.2 |
| SD11 | 44.99±3.09 | 14.06±0.95 | 4.0±0.2 | 0.23±0.01 | 31.60±1.32 | 13.12±0.49 | 360±13 | 3.00±0.15 | 4.3±0.3 |
| SD12 | 43.43±3.12 | 10.85±0.82 | 0.82±0.07 | 3.1±0.2 | 11.62±0.46 | 4.64±0.20 | 75±3 | 40±2 | 0.89±0.07 |
| SD13 | 30.40±2.05 | 7.41±0.52 | 0.47±0.03 | 2.3±0.1 | 6.51±0.12 | 2.48±0.10 | 35±1 | 30±1 | 0.51±0.03 |
| SD14 | 48.33±3.09 | 15.10±1.01 | 4.2±0.2 | 0.25±0.01 | 34.15±1.46 | 14.29±0.52 | 425±17 | 3.0±0.2 | 4.7±0.3 |
| SD15 | 52.21±3.05 | 14.50±0.98 | 2.9±0.2 | 2.2±0.1 | 29.73±1.29 | 13.00±0.50 | 280±11 | 28±1 | 3.2±0.2 |
| SD16 | 51.12±4.52 | 13.45±0.72 | 1.8±0.1 | 2.9±0.1 | 15.28±0.51 | 6.58±0.17 | 94±3 | 38.0±1.7 | 1.9±0.1 |
| SD17 | 39.74±3.02 | 11.68±0.88 | 2.91±0.20 | 0.95±0.07 | 24.22±0.89 | 10.63±0.35 | 240±10 | 12.0±0.5 | 3.2±0.2 |
| SD18 | 37.73±3.04 | 10.78±0.80 | 2.2±0.1 | 1.17±0.09 | 20.97±0.95 | 9.14±0.40 | 195±7 | 22±1 | 2.4±0.1 |

A census of the sweet drinks consumed by adult and teenager members of the Moroccan population was taken (Table 3).Eight groups of consumers were identified: 2750, 3310, 3720, 2680, 2796, 2589, 3568 and 2987 individuals drinking the SD1, SD2,SD6 and SD18,SD1, SD5, SD15

and SD18, SD7, SD11 and SD13, SD10, SD13, SD15 and SD18, SD1, SD11, SD16 and SD17, SD3, SD8, SD12 and SD17, SD1, SD10 and SD14, SD2, SD4, SD9 and SD16 sweet drinks corresponding to the AG1, AG2, AG3, AG4, AG5, AG6, AG7 and AG8 groups, respectively for adults, and four groups of consumers were identified: 3890, 2950, 3620 and 2560 individuals drinking the SD1, SD2,SD6, SD8, SD9, SD10 and SD16, SD1, SD3, SD8, SD12, SD15 and SD18, SD4, SD7, SD8, SD9, SD12, SD14, SD16 and SD17, SD2, SD5, SD6, SD8, SD11, SD13, SD17 and SD18 sweet drinks corresponding to the TG1, TG2, TG3 and TG4 groups, respectively for teenager groups.

Annual radon I($^{222}Rn$) intakes by adult and teenager members of the Moroccan population from the ingestion of the sweet drinks studied were determined (Table 3). The radon I($^{222}Rn$) intake ranged from (301±21) to (456±26 ) Bq $y^{-1}$, for adult groups, and from (381±31) to (790±71 ) Bq $y^{-1}$ for teenager groups, respectively.

### *3.2. Committed Effective Doses Due To $^{222}$Rn from the Ingestion of Various Sweet Drinks*

Annual committed equivalent doses due to $^{222}$Rn ($H_T(^{222}Rn)$) have been evaluated in the gastrointestinal compartments from the ingestion of different sweet drink samples by adult and teenager members of the Moroccan population (Equation (10)). Data obtained are shown in

The statistical relative uncertainty of the annual committed equivalent dose due to $^{222}$Rn determination is about 9%. $H_T(^{222}Rn)$ is influenced by the activity integral due to $^{222}$Rn in a tissue T from the sweet drink ingestion and mass $m_T$ of the target tissue (Equation (10)).Variation of the activity due to $^{222}$Rnas a function of time in different compartments of the gastrointestinal tract from the ingestion of the studied sweet drink samples were drawn. An example is given in Fig. 4 for the AG7 group of consumers (SD1, SD10 and SD14sweet drinks).

***Table 3.*** *Data obtained for the $^{222}$Rn intake ($I(^{222}Rn)$) from the ingestion of various sweet drinks by the members of the considered groups of consumers.*

| Group of consumers (number of individual) | Sweet drinks consumption (l y$^{-1}$) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SD1 | SD2 | SD3 | SD4 | SD5 | SD6 | SD7 | SD8 | SD9 | SD10 | SD11 | SD12 | SD13 | SD14 | SD15 | SD16 | SD17 | SD18 | Total (l y$^{-1}$) | |
| **AG1 (2750)** | **4±63** | **3±43** | | | | **3±37** | | | | | | | | | | | | **2±29** | **11±172** | **26±330** |
| AG2 (3310) | 4±60 | | | | 4±56 | | | | | | | | | | 3±48 | | | 1±17 | 10±181 | 28±349 |
| AG3 (3720) | | | | | | | 3±51 | | | | 3±49 | | 3±56 | | | | | | 8±156 | 23±341 |
| AG4 (2680) | | | | | | | | | | 4±52 | | | 4±58 | | 4±51 | | | 2±19 | 12±180 | 30±433 |
| AG5 (2796) | 4±59 | | | | | | | | | | 3±45 | | | | | 3±39 | 2±23 | | 10±166 | 29±363 |
| AG6 (2589) | | | 3±42 | | | | | 3±39 | | | | 3±40 | | | | | 3±43 | | 11±164 | 36±460 |
| AG7 (3568) | 4±72 | | | | | | | | | 3±57 | | | | 3±48 | | | | | 10±177 | 37±466 |
| AG8 (2987) | | 3±44 | | 4±53 | | | | | 3±45 | | | | | | | 2±30 | | | 10±172 | 32±455 |
| TG1 (3890) | 3±46 | 2±30 | | | | 1±15 | | 2±25 | 3±35 | 2±42 | | | | | | 3±37 | | | 16±230 | 46±578 |
| TG2 (2950) | 4±52 | | 3±42 | | | | | 3±32 | | | | 3±39 | | | 4±47 | | | 1±11 | 18±223 | 34±488 |
| TG3 (3620) | | | | 3±40 | | | 3±38 | 2±28 | 3±40 | | | 4±42 | | 3±37 | | 4±44 | 4±45 | | 26±314 | 60±860 |
| TG4 (2560) | | 3±37 | | | 3±35 | 1±10 | | 3±30 | | | 3±33 | | 4±42 | | | | 4±48 | 0.5±7.0 | 22±242 | 54±679 |

It can be noted from results given in Table 4 that committed equivalent doses due to $^{222}$Rn are clearly higher in the lower large intestine and upper large intestine than in the other organs of the gastrointestinal system for all groups of consumers. This is due to the fact that the former organs show higher activity integral than the others. It is to be noted that committed equivalent doses due to $^{222}$Rn in the gastrointestinal compartments increase when the radon intake ($I(^{222}Rn)$) increases (Table 3).For a given organ of the gastrointestinal system one notices that the committed equivalent dose calculated for the groups of adults is smaller than that calculated for teenager groups.This can be explained by two factors influencing the committed equivalent dose; firstly the mass of a tissue given for the teenager groups is smaller compared with that of the adult groups (Table4), secondo the intake of $^{222}$Rn is larger for the teenager groups compared with that for the adult groups (Table3).

***Table 4.*** *Annual committed equivalent dose due to $^{222}$Rn ($H_T(^{222}Rn)$) in the gastrointestinal compartments from the ingestion of sweet drinks by the members of the considered groups of consumers.*

| Group of consumers | $H_T(^{222}Rn)$ ($10^{-7}$ Svy$^{-1}$) | | | |
|---|---|---|---|---|
| | Stomach ($m_T$=0.15kg) | Small intestine ($m_T$=0.64kg) | Upper large intestine ($m_T$=0.21kg) | Lower large intestine ($m_T$=0.16kg) |
| AG1 | 0.1±2.1 | 0.1±2.3 | 0.6±10.2 | 0.6±9.9 |
| AG2 | 0.1±2.2 | 0.1±2.4 | 0.7±10.8 | 0.7±10.5 |
| AG3 | 0.1±2.2 | 0.1±2.3 | 0.7±10.6 | 0.7±10.2 |
| AG4 | 0.1±2.8 | 0.2±3.0 | 0.8±13.4 | 0.8±13.0 |
| AG5 | 0.1±2.3 | 0.1±2.5 | 0.7±11.3 | 0.7±11.0 |
| AG6 | 0.2±3.0 | 0.2±3.2 | 0.9±14.3 | 0.9±13.8 |
| AG7 | 0.2±3.0 | 0.2±3.2 | 0.9±14.4 | 0.9±14.0 |
| AG8 | 0.2±2.9 | 0.2±3.1 | 0.9±14.1 | 0.9±13.7 |
| TG1 | 0.2±3.9 | 0.3±4.2 | 1±20 | 1±20 |
| TG2 | 0.2±3.3 | 0.2±3.6 | 1±17 | 1±16 |
| TG3 | 0.4± 5.8 | 0.4±6.3 | 2±30 | 2±29 |

Committed effective dose due to $^{222}$Rn from the ingestion of the studied sweet drinks by adult and teenager groups of the Moroccan population were evaluated by using this method and dose conversion coefficients given inliterature [23, 24. Data obtained are in good agreement with each other (Table 5). A maximum value was found equal to 7.9 µSv $y^{-1}$ for the TG3 teenager group (Table 5)

***Table 5.****Committed effective doses due to $^{222}$Rn ($E_{Rn}$) from the ingestion of sweet drinks by adult and teenager members of the Moroccan population.*

| Group of consumers | $E_{Rn}$ ($10^{-7}$ Svy$^{-1}$) | | |
|---|---|---|---|
| | This method | Sharma et al. | Brown and Hess |
| AG1 | 30±2 | 27.06 | 29.04 |
| AG2 | 32±2 | 28.62 | 30.71 |
| AG3 | 31±2 | 27.96 | 30.01 |
| AG4 | 40±3 | 35.51 | 38.10 |
| AG5 | 33±2 | 29.77 | 31.94 |
| AG6 | 42±3 | 37.72 | 40.48 |
| AG7 | 43±3 | 38.21 | 41.01 |
| AG8 | 42±3 | 37.31 | 40.04 |
| TG1 | 53±4 | 47.40 | 50.86 |
| TG2 | 45±4 | 40.02 | 42.94 |
| TG3 | 79±6 | 70.52 | 75.68 |
| TG4 | 62±5 | 55.68 | 59.75 |

Which is lower than the mean world value for ingestion (ranging from 0.2 to 0.8 mSv $y^{-1}$) [25]. The dose conversion coefficient for $^{222}$Rnin the stomach for an annual sweet drink intake ranging between (156±8) l and (314±26) l (Table 3) was found to be equal to (9.2±0.6) x$10^{-8}$Sv $Bq^{-1}$. Sharma et al.[23] and Brown and Hess[24] found dose conversion coefficient for $^{222}$Rn in the stomach equal to 8.2 x$10^{-8}$Sv $Bq^{-1}$ for an annual water intake of 182.5 l, respectively.

# 4. Conclusion

It has been shown by this study that by using CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) one can evaluate $^{222}$Rn and $^{220}$Rnα-activities per unit volume inside and outside different sweet drink samples. It has been shown that $^{222}$Rn α-activity measured in residual gases of the sweet drink samples studied represents6 % to 10% of the global $^{222}$Rn α-activity of the sweet drinksstudied. Therefore, consumers should avoid drinking sweet drinks directly from bottles. Annual committed equivalent doses due to $^{222}$Rnwere determined in different organs of eight groups and four groups of adult and teenager Moroccan consumers, respectively. It has been shown that the annual committed equivalent dose due to $^{222}$Rn in the gastrointestinal organs depends on the mass of the target tissue, $^{222}$Rnintake and $^{222}$Rn α-activity integral. This SSNTDs' technique which has the advantage of being inexpensive, sensitive, and accurate and does not need the use of any standard solution for its calibration is a good tool for assessing radiation-dose risk due $^{222}$Rn intake from the ingestionof sweet drinks and other liquids.

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