MEASUREMENT OF RADON EMANATIONS
FROM PHOSPHATES AND CONVERSION FACTOR
USING POLYCARBONATE DETECTORS

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Abstract
Radon is considered as the main source of man’s exposure to ionizing radiation. It is a naturally occurring radioactive gas, its concentration in air depends mainly on the presence of Uranium or Thorium in the subsoil of the earth. The present study aims to demonstrate the possibility to use Solid State Nuclear Track Detectors (SSNTD) to evaluate radon concentration, particularly emanating from phosphates, and the conversion factor; allows to estimate from the radon mass activity the value of the Uranium concentration $C = 2.7 \pm 0.5 \text{[ppm]}/[\text{Bq/Kg}]$. The choice of the CR-39 SSNTD has been dictated by its sensitivity to all energies of alpha particles involved in measuring radon and its daughters.

Keywords: Radon; Uranium; Phosphate; SSNTD; CR-39; Calibration factor; Conversion factor.

1. Introduction
Radon is a radioactive gas that comes from the decay of the Uranium and Thorium present in the Earth’s crust, notably in phosphates. Its decay gives birth to radioactive elements then to lead. Radon belongs into chemical classification of rare gases, such as the neon, the krypton, the Xenon, ... Radon possesses three natural isotopes; $^{222}$Rn, $^{220}$Rn and $^{219}$Rn daughters of isotopes $^{226}$Ra, $^{224}$Ra and $^{223}$Ra belonging to radioactive families of $^{238}$U, $^{235}$U and $^{232}$Th.

This radioactive gas passes in the surrounding atmosphere, by diffusion and convective transport [1], and constitutes the main source of natural radioactivity in mining exploitations as well as in dwelling [2-5]. Its is, therefore, necessary to measure it for radioprotection purposes.

The respiratory way is the main penetration way of radon in the human organism. After inhalation, the radon is rapidly reexhaled, because it has a little affinity with biological medium notably with lungs. However, its daughters particles settle in along the lungs depending on their granulometric distribution and on the equilibrium state between radon and its daughters in the air [6]. Some of these daughters are alpha transmitters (see Table I), which have a very short radioactive life (some minutes) that limits their action to the site of deposit, especially to the level of the bronchic-epithelium cells that can then enter in cancerization process [7-11].

The present study aims to demonstrate the possibility to use SSNTD to evaluate; radon concentration, particularly emanating from phosphates, calibration factor and conversion factor; allows to estimate from the radon mass activity the value of the Uranium concentration.

2. Object and application area
The present study proposes a cheap and simple technique enabling to determine radon concentration, as emanation from Moroccan phosphates, as well as the $^{238}$U contents. This method is based on the utilization of SSNTD polymeric, sensitive to the alpha particles emitted by the radon and its daughters.

The damaged zone, called latent track, has to be revealed chemically to become observable by optical microscope. The number of the observed tracks is proportional to the average of radon volumic activity per exposure time of SSNTD.

Permanently emanating from phosphates, $^{222}$Rn can be used as, an indicator of radionuclides present in these minerals. In the absence of precautions on the sites of extraction, treating, or deposit, after its inhalation, it could have, an important risk due to its radioactivity and the radioactivity of its daughters [12-18].

Alone, the $^{222}$Rn isotope is used to follow the phosphates radioactivity because its half life is longer (3.8 days) and it is largely predominant in relation to the two other isotopes. Elsewhere, in the case of used phosphate samples, the $\gamma$-spectrometry has demonstrated only the significant presence of $^{238}$U and its daughters.

3. SSNTD description
The polymeric detector used is a polycarbonate (allyl diglycol) 750 µm thick, transparent, commercialized under the name of CR-39. It is sensitive to all energies of alpha particles involved in measuring radon, between 0 and 7.7 MeV.

Tracks etching was realized in a bath of 6.25 N NaOH solution, at 70°C during 7 hours. The counting was obtained using the ocular microscope and/or the image analyzer system.
4. Idea of can measure
Experimentally, we have used cylindrical polymeric cans 4.5 to 18 cm of diameter; their tightness has been insured by a silicone dough. On the internal can surface is fixed a square centimeter piece of CR-39 SSNTD. 20 to 500 g mass of phosphates was put in the bottom. The distance between SSNTD and the superior surface of phosphates was superior to 7 cm, so as to measure solely alpha particles emitted by radon and its daughters possess energy inferior or equal to 7.7 MeV. The maximal range in the air of these alpha particles, which correspond to the emission of $^{214}$Po, is 6.8 cm.

5. Radon and its daughters action mode
The alpha particles detected during the analysis of an atmosphere loaded in radon become from the radioactive decay of $^{222}$Rn, $^{218}$Po and $^{214}$Po (Table 1). The thickness of CR-39 used in this study is 750 µm.

<table>
<thead>
<tr>
<th>Radionuclides</th>
<th>Half life</th>
<th>Alpha energy</th>
<th>Range in air (mm)</th>
<th>Range in CR-39 (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}$Rn</td>
<td>3.8 d</td>
<td>5.5</td>
<td>41</td>
<td>30</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>3.11 mm</td>
<td>6</td>
<td>47</td>
<td>38</td>
</tr>
<tr>
<td>$^{214}$Po</td>
<td>1.610^{-5}s</td>
<td>7.7</td>
<td>68</td>
<td>54</td>
</tr>
</tbody>
</table>

Table 1: Alpha particle range in air and in SSNTD (CR-39) emitted by the radon, $^{210}$Po and $^{214}$Po.

6. Calibration factor and Conversion factor
The calibration factor $K$ of CR-39, expressed in $[\text{tr./cm}^2/\text{d}]/[\text{Bq/m}^3]$, allows to transform the density of observable tracks to the radon concentration [20]:

$$D = KA.$$ 

It depends on the radius $r$ of the can measure

$K = 0.285$ for $r \geq 4.85$ cm,

and $K = 0.0114 \times (10 - r)$ for $r < 4.85$ cm.

Conversion factor allows to estimate the $^{238}$U concentration in ppm contained in a phosphate sample, from the measure of the radon mass activity emanating or vice versa. It saves time by avoiding repeated the measure of samples elementary constituent, calculations of ranges in its materials as well as the calibration.

The tracks density of SSNTD exposed in the measure can air according to the radon volumic activity $A_{Rn}$ and the track density of SSNTD in direct phosphate contact according to the volumic activity of the Uranium $A_U$ are respectively [20]

$$D_{Rn} = \frac{1}{4} \cos^2 \theta \cdot A_{Rn} \sum R_i ;$$

$$D_U = \frac{1}{4} \cos^2 \theta \cdot A_U \sum R_i'.$$

$R_i$ and $R_i'$ are respectively, the range in the air and in the phosphates, of $\alpha$ particles with the energy $E_i$, and the critical angle $\theta_c$.

7. Results and discussion
In each measure can of 175 mm$^3$, containing 40 g of 80 µm diameter grains phosphates, SSNTD are exposed during a time ranging from 1 to 17 days. The average value of the mass activity of the used phosphate is $77 \pm 11$ Bq/Kg. The volumic activity in this can is $17140 \pm 2400$ Bq/m$^3$. The following factors were taken into consideration: the radius of the can, effects of edge, and the contribution of the deposited radionuclides on surfaces.

Some CR-39 detectors were exposed to the measure cans radon (20 cm of diameter) while others were in contact with phosphates samples during variable times. The radon in the measure cans emanated from phosphates.

The conversion factor $C$ allows to estimate from the radon mass activity, expressed in $[\text{Bq/Kg}]$, the value of the Uranium concentration in $[\text{ppm}]$ for a 80 µm granulation size of phosphates sample. Its average value is $C = 5 \pm 0.5$ [ppm]/[Bq/Kg].

The $^{238}$U concentration in phosphates samples, as calculated by conversion factor, is $207 \pm 41$ ppm. This value can be compared with the value of $209 \pm 15$ ppm [21].

8. Conclusion
The proposed technique, using CR-39, appears suitable for measuring of the radon emanating from phosphates, because it is reproducible, very sensitive, well adapted to long-duration testing and is extremely simple to implement.

These characteristics make the technique practical in radioprotection, for phosphates industry workers and dwelling, especially in regions rich in phosphate or in granite. They also make it useful in the areas earth sciences, such as:
- Uraniferous prospecting,
- hydro-geological prospecting,
- break localization and geological structures,
- seismic prediction, and
- volcanic prediction.

References
[10] National Research Council (NRC) - Comparative dosimetry of radon in mines and homes.