Measurement of radon gas concentration and effective dose in water from the Midelt region of Morocco, Using nuclear track detectors (LR-115)

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Abstract. The article's objective is to evaluate the concentration of radon in different water samples, with levels ranging from 0.31 Bq/L to 2.24 Bq/L, the annual effective dose ranged from 2.09 to 8.83 (mSv/y). Radon (222Rn), a radioactive gas originating from the decay of 238U in the 226Ra decay series, is commonly found in rocks, soil, natural gas, and groundwater. Exposure to radon in both air and water can lead to human radiation exposure, potentially increasing the risk of specific types of cancer.

The primary goal of this study is to measure radon levels in water samples from various locations in Morocco, specifically in the Midelt province and Daraa-Tafilalt region (located at 32° 40' 48″ North, 4° 44' 24″ West), using Solid State Nuclear Track Detectors of LR-115 type, It's important to mention that all the analyzed water samples recorded annual effective doses that fall within the global average recommended levels for ingestion exposure dose values set by the United Nations Scientific Committee on the Effects of Atomic Radiation. Based on these findings, there appear to be no radiation risks associated with radon gas in the study area.

1 Introduction

Radon (222Rn) is a radioactive gas that forms naturally through a process of radioactive decay. The element that gives rise to radon is uranium-238 (238U), a radioactive element present in the earth's crust in varying concentrations. When uranium-238 decays, it gives rise to radium-226 (226Ra) through a series of radioactive reactions. Radium-226, in turn, continues to decay, emitting alpha particles and producing several decay products, including radon-222. This radon-222 is often referred to as the "son radon" of radium-226, as it is generated by its decay [1]. Radon is a gas whose particularity lies in the fact that it does not result from a chemical reaction, but rather from a radioactive decay process. More precisely, it is formed when the radioactive element radium-226 undergoes a transformation, emitting alpha particles. These alpha particles are made up of two protons and two neutrons, and are expelled during the decay process. An interesting aspect of this process is that radon does not remain alone. As it decays, it generates a temporary by-product known as polonium-218. Polonium-218 is itself a radioactive element, and is also subject to further decay. An important point to note is radon's lifespan. This radioactive gas has a relatively short half-life of 3.8 days. This means that half the amount of radon present will transform into other radioactive elements in just 3.8 days. This characteristic makes radon particularly radioactively unstable [2]. Water-soluble Radon can pose a significant risk when present in high concentrations in drinking water, as it can be absorbed by the body. According to biokinetic models, after ingestion, the short-lived daughter products of Radon remain in the stomach for only a few minutes before entering the bloodstream and being promptly excreted from the body [3]. Testing for 222Rn in water is crucial in reducing potential exposure. However, the use of water in residential areas can lead to increased internal concentrations of 222Rn depending on the total amount of water used, the size of the area, and the level of ventilation [4]. Radon can pose a serious risk to people living in areas where it can spread beyond its conversion to polonium, which extracts alpha particles and can contaminate plants and homes. Radiation is a type of energy emitted by radioactive substances [5].

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2 Materials and Methods

Water samples were collected from various parts of the Midelt region and stored in plastic containers. Each container held 1/4 liter of water, and a 2 × 2 cm nuclear track detector (LR-115) was installed on the inner surface of the container lid. The container was then covered for one month to allow equilibrium between the radon gas in the water and the radon in the air above the water [6].

After one month, the track detectors werechemically treated for two hours using 2.5 M NaOH solution at a temperature of 60°C. The treatment revealed that each alpha particle left a small hole in the red layer, ranging from 1 to 15μm in width [7].

The track density recorded on each detector was calculated from equation:

\[ \rho = \frac{\sum N_i}{nA} \]  

where \( \rho \) is the track density, 
\( N_i \) refers to the number of tracks counted in the first period of view, 
\( A = \) is the area of the field of view in cm², and \( n = \) is the total number of small holes in the red layer [8].

The Radon activity concentration \( C \) in the water can be estimated through the following empirical equation (El-Araby et al., 2019):

\[ C = \frac{\rho}{Kt} \]  

where \( K \) is the calibration factor (\( K = 0.201 \) tracks cm⁻²/Bqm⁻³ d) of the LR-115 detector, 
\( t = \) is the exposure time in, days [9].

![Fig. 1. Map showing the locations of the studied samples in the Midelt region (Morocco).](image-url)
Fig. 2. An illustrative chart outlining the process of detecting radon in water[9].

Calculation of annual effective dose

This formula provides a method for computing the yearly effective radiation exposure caused by radon:

$$E = C \times H \times F \times T \times D$$  \hspace{1cm} (3)

Here's what each component of the formula represents:

$E$: The annual effective dose of radon, typically expressed in units of sieverts (Sv) or millisieverts (mSv).

$C$: The radon concentration in the air, typically measured in units of becquerels per cubic meter (Bq/m). This represents the amount of radon gas present in the air.

$H$: The occupancy factor, which represents the fraction of time that the building is occupied. This is typically assumed to be 0.8, meaning that the building is occupied for 80% of the year.

$F$: The equilibrium factor, which represents the ratio of the concentrations of radon progeny (i.e., the radioactive decay products of radon) to the concentration of radon itself. This factor takes into account the fact that radon progeny can attach to dust particles and other surfaces in the building, and can be inhaled or ingested by occupants. The equilibrium factor is typically assumed to be 0.4.

$T$: The time factor, which represents the amount of time that radon and its progeny remain in the air. This factor takes into account the fact that radon and its progeny decay over time. The time factor is typically calculated based on the half-life of radon and its progeny, and is expressed as a function of the number of hours per day that the building is occupied. The time factor is typically assumed to be 0.5 for residential buildings and 0.7 for workplaces.

$D$: The dose conversion factor, which represents the amount of radiation dose that is absorbed by the body per unit of radon exposure [10]. This factor takes into account the fact that different tissues in the body are more or less sensitive to radiation, and that different types of radiation (alpha, beta, gamma) have different biological effects. The dose conversion factor for radon is typically expressed in units of sieverts per unit of radon concentration (mSv/Bq/m).

To calculate the annual effective dose of radon, you would need to know the values of $C, H, F, T, and D$, and then multiply them together as indicated by the formula. For example, if the radon concentration in a home is $200 \text{ Bq/m}$ the occupancy factor is 0.8, the equilibrium factor is 0.4, the time factor is 0.5, and the dose conversion factor is $8 \text{ mSv/Bq/m}$, then the annual effective dose of radon would be:

$$E = 200 \text{ Bq/m} \times 0.8 \times 0.4 \times 0.5 \times 8 \text{ mSv/Bq/m} = 25.6 \text{ mSv}$$

So the annual effective dose of radon in this home would be 25.6 millisieverts. It's worth noting that the recommended action level for radon in homes varies depending on the country, but in general, levels above $100 \sim 200 \text{ Bq/m}$ are considered to be a cause for concern and may require mitigation measures [11].
3 Results and Discussion

The Midelt region of Morocco is known for its granite-rich geology, the presence of granitic rocks in this region has important implications for the concentration of radon gas in groundwater, when granitic rocks are present in an area, they can release radon into groundwater formations. This radon can then dissolve in water, potentially leading to high levels of radon gas in local wells and water sources. Consumption of water containing high levels of radon can pose risks to human health, as prolonged exposure to this radioactive gas is associated with an increased risk of lung cancer.

Water samples were collected from various sources in Midelt, including rivers, well water and dams. The highest concentration of radon founded in well water, with a concentration of $2.24 \text{ Bq/L}$. The results showed that the concentration of radon in rivers and dam water is lower at $0.31 \text{ Bq/L}$, and the average concentration is $1.15 \text{ Bq/L}$. This difference in concentration is due to the depletion of radon gas with well water being the most exposed, in contrast of the results with the reference levels of radon in water set by international organizations, such as the Environmental Protection Agency (EPA) with a highest allowed value in water of $0.14 \text{ Bq/L}$ and the International Commission Radiation.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Type of water</th>
<th>Tracks density (track. mm$^{-2}$)</th>
<th>Concentration (Bq/L)</th>
<th>Effective annual dose (mSv/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>Wells water1</td>
<td>211.4</td>
<td>2.24</td>
<td>8.83</td>
</tr>
<tr>
<td>S 2</td>
<td>Wells water2</td>
<td>188.6</td>
<td>1.98</td>
<td>7.80</td>
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<tr>
<td>S 3</td>
<td>Wells water3</td>
<td>167.7</td>
<td>1.76</td>
<td>6.94</td>
</tr>
<tr>
<td>S 4</td>
<td>Wells water4</td>
<td>125.9</td>
<td>1.32</td>
<td>5.20</td>
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<td>S 5</td>
<td>Dams water1</td>
<td>99.3</td>
<td>1.04</td>
<td>4.10</td>
</tr>
<tr>
<td>S 6</td>
<td>Dams water2</td>
<td>97.4</td>
<td>1.02</td>
<td>4.02</td>
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<tr>
<td>S 7</td>
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<td>77.45</td>
<td>0.81</td>
<td>3.19</td>
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<td>S 8</td>
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<td>73.65</td>
<td>0.72</td>
<td>2.83</td>
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<td>Rivers water2</td>
<td>37.55</td>
<td>0.35</td>
<td>2.09</td>
</tr>
<tr>
<td>S 10</td>
<td>Rivers water3</td>
<td>29.95</td>
<td>0.31</td>
<td>1.22</td>
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<tr>
<td>average</td>
<td></td>
<td>110.89</td>
<td>1.15</td>
<td>4.53</td>
</tr>
</tbody>
</table>

Table 1. Radon concentrations and effective annual dose in water for different areas Midelt region

The table presents the results of the analysis of radon concentration in water samples collected from various sources in Midelt, Morocco. Each water sample is identified by a sample code (S1, S2, . . .) and the type of water (well water, dam water, river water). The next two columns indicate the track density (track. mm$^{-2}$) and radon concentration (Bq/L) for each water sample. Track density is a measure of the radioactivity of the water sample and is used to calculate the radon concentration in the water.

The last row of the table gives the average radon concentration for all the water samples analyzed. The results show that the concentration of radon is higher in well water than in dam water and river water, with an average concentration of $2.24 \text{ Bq/L}$. Radon concentrations in dam water and river water are lower, with an average concentration of $0.31 \text{ Bq/L}$ and an overall average concentration of $1.15 \text{ Bq/L}$.

These results are important because they suggest an increased exposure to radon for people who consume well water in the Midelt region. The radon concentrations in well water samples exceed the reference levels established by international organizations for safe drinking water. These reference levels are $0.14 \text{ Bq/L}$ for the US Environmental Protection Agency (EPA) and $0.59 \text{ Bq/L}$ for the International Commission on Radiological Protection (ICRP).

Regular monitoring of radon concentration in drinking water is therefore essential to protect human health and prevent risks associated with exposure to this radioactive substance. The results of this study also highlight the need to identify the sources of high radon concentration in well water and implement measures to reduce radon levels in drinking water.
Wells appear to have the highest annual radiation doses of the three water source categories, with values ranging from 5.20 mSv/y to 8.83 mSv/y. This suggests that water from wells may be more radioactive than water from other sources. Dams have slightly lower annual radiation doses than wells, with values ranging from 3.19 mSv/y to 4.10 mSv/y. Water from dams have the lowest dose of all sources listed. Rivers have the lowest annual radiation doses of the three water source categories, with values ranging from 1.22 mSv/y to 2.83 mSv/y. Water from rivers have the lowest dose of all sources listed in the table. On average, all water sources combined have a mean annual radiation dose of 4.53 mSv/y. This could be interpreted as the average dose that people could be exposed to by drinking water from these sources in the specific region or context where these data were collected. Regular monitoring of radon gas levels in water samples from the Midelt region is therefore essential to ensure that radiation safety standards are met. Mitigation measures can be taken if radon levels are too high, including ventilation of water wells to allow radon to escape into the atmosphere.

4 Conclusion

The study highlights the potential risks associated with exposure to high levels of radon in water, particularly in regions with granitic bedrock such as the Midelt area. The results indicate that the highest concentration of radon gas is found in well water, unlike river water and dams, which are less concentrated, and that regular monitoring of the concentration of radon gas in drinking water is necessary to protect human health. The findings suggest the need for appropriate measures to be taken to reduce exposure to radon in well water, including the use of radon removal systems, improved well construction and maintenance, and the implementation of regulations to reduce exposure to radon in drinking water. Overall, the study emphasizes the importance of addressing the issue of radon exposure in drinking water to protect public health.

References