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**Original Article**

# Assessment of Effective Dose Equivalent from Internal Exposure to 222Rn in Ramsar City

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## Abstract

**Introduction**
In this study, effective dose equivalent for the public due to internal exposure to $^{222}$radon ($^{222}$Rn) was evaluated in three regions of Ramsar, a northern coastal city in Iran.
**Materials and Methods**
Measurements were carried out using a radon monitoring device. Outdoor and indoor radon concentrations were measured within 24 hours with an integration interval of 3 hours. Regions were selected with respect to our previous study on areas of Ramsar with high levels of environmental background radiation.
**Results**
This study showed that indoor $^{222}$Rn concentration reached to 465 Bq/m$^3$ in one of the selected regions (Talesh Mahalleh) in early morning (5-8 a.m.). Our study also showed that the average effective dose equivalents (due to both indoor and outdoor exposures) in the selected regions (Talesh Mahalleh, Sadat Mahalleh, and Chaparsar) were 9.5±2.8, 5.1±2.1, and 3.2±1.2 mSv/y, respectively.
**Conclusion**
It is clear that the annual effective dose from internal exposure to $^{222}$Rn in areas of Ramsar with high levels of natural radiation was significantly higher than the maximum annual effective dose permissible for public.

**Keywords:** Effective Dose; Internal Exposure; Radon; Ramsar

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# 1. Introduction

According to a report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the average annual exposure to natural radiation sources is 2.4 mSv, worldwide [1]. However, in Ramsar, a northern coastal city in Iran overlooking the Caspian Sea, environmental exposure can reach high levels similar to some inhabited regions where the soil displays abnormally high radionuclide concentrations.

Many radionuclides are found naturally in terrestrial soils, rocks, and building materials (derived from the soils and rocks) [2, 3]. Upon decay, these radionuclides produce an external radiation field to which all human beings are exposed. In terms of dose, the principal primordial radionuclides include $^{40}$K, $^{232}$Th, and $^{238}$U [4]. In some cases, this exposure exceeds that of all man-made sources combined [2, 5-10].

Many recent studies about radon were performed following international conferences at Salzburg (Austria) Rimini (Italy), Montreal (Canada), Prague (Czech Republic), Fukuoka (Japan), and Athens (Greece) (1999) [11-16]. Moreover, a valuable synthesis of European research on this subject has been recently published [17]. The available information can improve the understanding of environmental processes that affect radon exposure. However, there are still many problems associated with the accurate assessment of exposure to individuals and populations.

Some radiological studies in Ramsar and high-level environmental background radiation areas (HLEBRAs) were carried out over a decade ago on public doses and the associated health-related and biological effects [8, 9, 18-20]. However, due to the dynamic nature of such areas, further detailed periodic studies on possible epidemiological variations are required.

According to a report by UNSCEAR [21], radon and its progeny are responsible for half of the total annual effective dose due to natural background radiation. In fact, radon and its short-lived decay products in the atmosphere are the most important contributors to human exposure from natural sources.

Although health risks associated with high radon exposures in underground mines have been recognized for a long time, relatively little attention was paid to environmental radon exposure until the 1970s. Moreover, some researchers began to realize that indoor radon exposure might be quite high in some areas, compared to exposures experienced by many underground miners [21].

In this study, we aimed to measure indoor and outdoor $^{222}$Ra concentrations in some HLEBRAs of Ramsar city and assess the effective dose equivalent for public due to internal exposure. HLEBRAs were selected according to our previous study in Ramsar [5].

It is acclaimed that inhalation of short-lived $^{222}$Rn decay products and their subsequent deposition along various airway walls of bronchial tree provides the main pathway for radiation exposure of the lungs. This type of exposure is mostly produced by alpha particles, emitted by several of these radionuclides, although some beta particles and gamma radiation are also emitted. There is a general agreement among researchers that alpha particle irradiation of secretory and basal cells in the upper airways is responsible for the risk of lung cancer [1].

Since solar heating during daytime tends to induce some turbulence, radon is more readily transported upwards and away from the ground. At night and during early morning hours, atmospheric (temperature) inversion conditions are often found, which tend to trap radon closer to the ground [21]. In other words, radon concentrations can vary diurnally. In this paper, we also attempted to show variations in indoor and outdoor radon concentrations during 24 hours a day in HLEBRAs of Ramsar.

# 2. Materials and Methods

The present study was carried out in three houses in Ramsar city in three separate HLEBRAs (three houses in each region including Sadat Mahalleh, Chaparsar, and Talesh Mahalleh) around and near hot water springs. Measurements were performed during the winter of 2014. Regions were selected according to our previous study [5, 22].

Indoor and outdoor measurements were carried out using a radon monitor (SARAD, Germany) for 24 hours with an integration interval of 3 hours (8 measurements at each point). The sensitivity of the radon monitor for 100Bq/cm$^3$ radon concentration was 17% with a three-hour integration time. Another evaluated region was located near the seashore with low environmental background radiation.

The effective dose equivalent (E) due to public exposure from $^{222}$Rn was calculated outdoors ($E_{out}$) and indoors ($E_{in}$), using $^{222}$Rn concentration to dose conversion factor of 9 nSv h$^{-1}$ per Bq m$^{-3}$ equilibrium equivalent concentration (EEC) for inhalation and 1.5 µSv year$^{-1}$ per Bq m$^{-3}$ for radon dissolved in tissue, recommended by UNSCEAR [21].

$$E_{out} = C_{Rno} \times 0.8(\text{EEC}) \times 9 \text{ nSv h}^{-1} \text{ per Bq m}^{-3}(\text{EEC}) \times 0.2(\text{occupancy factor}) \times 8760 \text{ h year}^{-1} \quad (1)$$

$$E_{in} = C_{Rni} \times 0.4(\text{EEC}) \times 9 \text{ nSv h}^{-1} \text{ per Bq m}^{-3}(\text{EEC}) \times 0.8(\text{occupancy factor}) \times 8760 \text{ h year}^{-1} \quad (2)$$

$$E_{i\&o} = [C_{Rno} \times 0.2] + [C_{Rni} \times 0.8] \times 1.5 \text{ µSv year}^{-1} \text{ per Bq m}^{-3} \quad (3)$$

$$E = E_{out} + E_{in} + E_{i\&o} \quad (4)$$

Where, $C_{Rno}$ and $C_{Rni}$ are outdoor and indoor $^{222}$Rn concentration, respectively; and $E_{i\&o}$ is the effective dose equivalent of $^{222}$Rn dissolved in tissue.

Radon monitor was equipped with sensors for measuring temperature, pressure, and relative humidity during each integration interval.

## 3. Results

Figures 1 and 2 show indoor and outdoor radon concentrations (Bq/m$^3$) in four different regions of Ramsar. Time interval for integration was set at three hours in the monitoring device; thus, we could obtain 8 readings per day. As depicted in these figures, Talesh Mahalleh was the hottest region among these areas, and indoor radon concentration in this area was much higher than that reported outdoors.

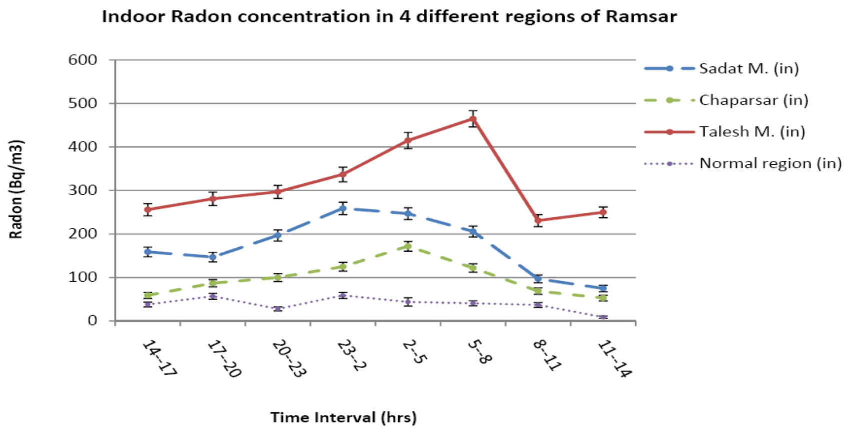

Figure 1. Indoor radon concentration (Bq/m$^3$) in four different regions of Ramsar

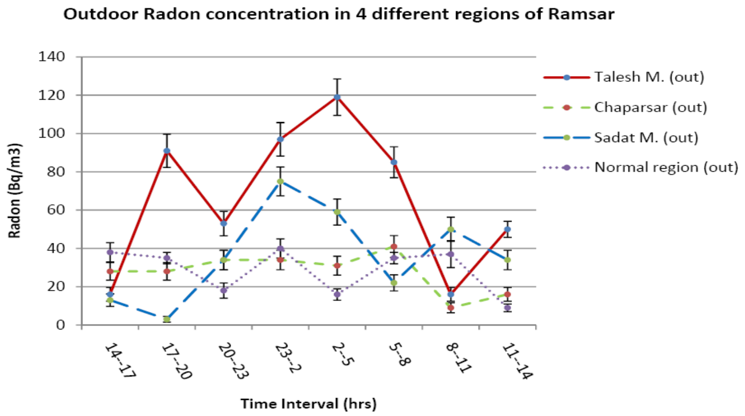

Figure 2. Outdoor radon concentrations (Bq/m$^3$) in four different regions of Ramsar

Table 1 shows the mean and maximum radon concentrations in different regions during daytime (8 readings). Table 2 presents the meteorological information.

Mean effective dose equivalent ($\bar{E}$) for public from exposure to $^{222}$Rn was calculated in different regions, using the suggested formula [21]. As the results indicated, the maximum dose was reported in Talesh Mahalleh (Table 3).

Table 1. Mean and maximum radon concentrations (Bq/m$^3$) in three different regions during daytime

| | Mean | | Maximum | |
|---|---|---|---|---|
| Regions | Indoor | Outdoor | Indoor | Outdoor |
| Talesh M. | 326±86 | 68±41 | 465 | 119 |
| Sadat M. | 173±66 | 40±24 | 259 | 75 |
| Chaparsar | 104±40 | 36±10 | 172 | 41 |

Table 2. Meteorological information in three different regions

| | Pressure (mbar) | | Relative humidity (%) | | Temperature (ºC) | |
|---|---|---|---|---|---|---|
| Regions | Indoor | Outdoor | Indoor | Outdoor | Indoor | Outdoor |
| Talesh M. | 1025 | 1015 | 59 | 73 | 19 | 10 |
| Sadat M. | 1012 | 1021 | 48 | 83 | 18 | 9 |
| Chaparsar | 1030 | 1028 | 79 | 73 | 11 | 10 |

Table 3. Mean effective dose equivalent ($\bar{E}$) for public (mSv/y) due to exposure to $^{222}$Rn in three different regions

| Regions | $\bar{E}$ (in) | $\bar{E}$ (out) | $\bar{E}$ (total) |
|---|---|---|---|
| Talesh M. | 8.22±2.17 | 0.86±0.52 | 9.49±2.80 |
| Sadat M. | 4.36±1.67 | 0.50±0.30 | 5.09±2.05 |
| Chaparsar | 2.62±1.01 | 0.45±0.13 | 3.21±1.19 |

## 4. Discussion

$^{222}$Ra and $^{220}$Rn are gaseous radioactive products of the decay of radium isotopes $^{226}$Ra and $^{224}$Ra, which are present in all terrestrial materials. Some atoms in these radon isotopes are released from the solid matrix of the material by recoil as radium decays [23]. The decay must occur within the recoil distance of the grain surface so that a radon atom can escape from the mineral grain into the pore space [23].

Outdoor radon concentrations are not only affected by the exhalation rate in the area, but are also influenced by the atmospheric mixing phenomena. Solar heating during daytime tends to induce some turbulence; therefore, radon is more readily transported upwards and away from the ground. In other words, radon concentrations can vary diurnally by a factor as high as ten [24].

In this study, some disturbances were reported during 24 hours in each region at night and during early morning hours. At these hours, atmospheric (temperature) inversion conditions were often reported, which tended to trap radon closer to the ground; this increased the radon concentration to the maximum level at these hours (Figure 1).

As many studies have shown, advection is usually the main factor when high rates of radon enter buildings [25]. This advection is driven by the pressure differential between the building shell and the ground around the foundation, produced due to higher temperatures within the shell, mechanical ventilation, and to some extent by wind blowing against the building.

The effectiveness of this differential pressure in pulling in radon-laden soil gas through the foundation is critically dependent on the effective permeability of both the building foundation and the adjacent earth. Higher indoor concentrations in HLEBRAs in this study (Table 3) may also be due to advection between the building shell and the ground around the foundation.

Radon dissolved in water may also enter the indoor air through de-emanation when using water. The contribution of water supply depends on radon concentration in water, used for activities such as showering and laundry, and can be sometimes of high significance. Radon concentrations in water may range over several magnitudes, generally being the highest in well water, intermediate in ground water, and lowest in surface water [26].

Radioactivity in HLEBRAs of Ramsar is also due to $^{226}$Ra and its decay products, which have been brought up to the earth surface by the water of more than 9 hot springs in these areas. These may contribute to higher radon concentrations over the HLEBRAs of Ramsar. In fact, the observed differences between our results and other studies [2, 3, 6, 27] may be due to the dynamic nature of hot springs around the HLEBRAs in Ramsar city.

Moreover, our estimation of the annual effective dose from internal exposure to $^{222}$Rn was based on readings during a 24-hour period; however; some changes in indoor and outdoor concentrations are predictable day-to-day and between seasons. These changes may be due to variations in atmospheric (temperature) inversion conditions, effective permeability of both the building foundation and the adjacent earth, and also the solubility of radon in water. Hence, further research is required in order to reach a more reliable conclusion.

## 5. Conclusion

The results of indoor and outdoor studies on internal exposure to $^{222}$Rn in Ramsar and its HLEBRAs showed that the annual effective doses in people living in some regions were higher than 9 mSv. It is clear that these ranges of effective dose are much higher than the permissible annual effective dose for public. Further and more extensive studies are required to clarify the effects of different seasons and months within seasons on indoor and outdoor concentrations to determine more definite annual effective doses in people living in these areas. The stimulus effects of radiation and susceptibility of people to the late effects of radiation exposure, in particular the impacts of radiation on epidemiology, radiobiology, and allergic diseases, could be other suitable fields for research.

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