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Concentration of radon (Radon 222 and Thoron) in indoor air Decorative stone of warehouses and the effective dose by staff; Minab, Iran

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Abstract: *Radon is a colorless, odorless half-life radioactive gas that that can be emission from Decorative stones such as granite, marble, etc. Inhaling Radon gas over a long period may increase the effective dose received and the subsequent increase in lung cancer among patients. In this cross-sectional-descriptive study, Radon 222 and Thoron concentrations was measured in four Decorative stones of warehouse by Radon meter portable RTM1688-2 model in three stages. In total, 24 concentrations of 24 hours of indoor air and 24 concentrations of 4 hours of Radon 222 and thoron of the background air were measured. Then, effective dose received of Radon 222 and Thoron was calculated by UNSCEAR and ICRP equations, respectively. The mean indoor air radon and background air were 74±37 and 34±16 Bq/m^3, respectively. The mean concentration of Radon of indoor air in Decorative stones of warehouses in DSW1, DSW2, DSW3 and DSW4 is 72.50±34, 98.25±43, 34.42±18 and 88.92±51 Bq/m^3. The mean effective dose received by the staff from Radon 222 and Thoron at 8 working hours is 0.53±0.18 and 0.05±0.03 mSv/y and in 16 working hours is 1.05±0.36 and 0.11±0.07 mSv/y, respectively. Also, the mean effective dose received by staff from Radon at 8 and 16 working hours is 0.58±0.2 and 1.16±0.41 mSv/y. Mean radon concentration in indoor air and the mean effective dose received by staff is lower than the standards level. Decorative stone of warehouses is the resources accumulation of Radon gas that can be reduced by doing corrective actions.*

Keywords: *Radon 222, Thoron, effective dose, Decorative stone and warehouses*

I. Introduction

Radon is a colorless, odorless radioactive gas which can be distributed from water, soil, stones and rocks .[2 ,1] Radon 222 (222Rn) results from the decay of radium-226 (226Ra) in the chain of uranium 235 (235U) and Thoron (220Rn) results from the decay of radium-224 (224Ra) in the chain of thorium 232 (232Th) .[4 ,3] Based on information provided by National Radiation Protection Board (NRPB), 85% of the effective dose received by humans are from natural radiation and 15% is synthetic (man-made) radiation .[5] Radon 222, Thoron and its girls account for 4.1 mSv of the annual effective dose received from natural radiation (2.4 mSv) (over 50 percent) .[7 ,6] The alpha radiation emitted by the Radon 222 and the girls (218Po and 214Po) can damage the DNA of lung cells and eventually cause lung cancer in the long term [8, 9]. After smoking, the second leading cause of death from lung cancer is Radon gas [9] . America Environmental Protection Agency (EPA) has announced the deaths from indoor air Radon approximately 21,000 persons per year which is 10 times higher than deaths from air pollution .[10] EPA and WHO for indoor air Radon are 148 and 100 Bq/m3, respectively .[11 ,10] International Commission on Radiological Protection (ICRP) has announced the maximum annual effective dose received by the staff of the indoor air Radon as 20 mSv/y [12] . Radon concentration in indoor air is mainly caused by emissions from building materials, the surrounding soil and water resources [13]. Although the half-life of Thoron (56 seconds) is less than the Radon-222 (3.82 days), but its risks, especially in closed places (warehouses, etc.) cannot be neglected .[15 ,14] In recent years, several studies on Radon gas emissions from building materials such as stone, granite, marble, etc. have been made -16] .[19 But less attention is paid to indoor air Radon concentration and effective dose received by staff in the warehouse for storage of materials, especially the Decorative stones. Hence, this study was an attempt to measure Radon concentration (Radon 222 and Thoron) of indoor and adjacent air (Background) at 4 Decorative stones of warehouses in Minab, Hormozgan Province, Iran. Then, the effective dose received by staff due to inhalation of gas Radon-222 and Thoron were calculated and compared with standards.

II. Materials and Methods

2.2 Measurement concentration of Radon 222 and Thoron

First, 4 major and important Decorative stones of warehouse at Minab city were selected. The measurement was done at three stages from November to April 2012 (one step per month). According to the instructions provided by the EPA, concentration measurement of indoor air Radon measurements should be taken at least 24 hours .[20] Hence, the concentration of Radon 222 and Thoron indoor air and Background the was measured for 24 and 4 hours, respectively by Radon meter portable RTM1688-2 model made in SARAD German companies. The sensitivity of this device in 150 minutes of continuous measurement is cts/ (min×KBq/m^3) 6.5 .[21] The device measure temperature, pressure and humidity as well as Radon 222 and Thoron concentrations and records them hourly. High sensitivity with alpha spectrometry analysis leads to a short response time even at low concentrations. According to measurement instructions provided by the SARAD Company, in the continuous measurement of more than 2 hours, to reduce the statistical error and double precision, the radon meter must be in a slow mode.[22 ,21] In each warehouse, the radon meter was placed at a height of 1 meter and in the centre of warehouse. At every stage of the warehouse, two 24-hour measurements and two 4-hour measurements was done. In total of three stages of 5 storage warehouse, 24 concentrations of 24-hour indoor air and 24 concentrations of 4-hour Radon 222 and Thoron of background air were measured.

2.2 Calculation of the annual effective dose received by staff

2.2.2. Effective dose received by the Radon 222

The annual effective dose received by the Radon 222 indoor air was calculated by Equation 1 presented from UNSCEAR;

Equation 1 $$ERn=C_{Rn} \times 0.4 \times T \times 9 \times 10^{-6}$$

In this equation; ERn is annual effective dose received, (mSv/y), C_{Rn} is geometric mean concentration of Radon 222 (Bq/m3), 0.4 equilibrium factor, T; daily working time that is 8 hours (2920 h/y) and 16 h (5840 h/y), 9 is conversion coefficient of Radon 222 concentration to the annual effective dose received, (nSv/Bq.m3.h) and 10-6 is Nano mSv conversion ratio to the mSv .[23]

2.2.2. Effective dose received from Thoron

The annual effective dose received by indoor air Thoron was also calculated by Equation (2) presented by UNSCEAR.

Equation 2 $$E_{Tn}= C_{Tn} \times 0.02 \times T \times 40 \times 10^{-6}$$

In this equation E_{Tn}; annual effective dose received (mSv/y), C_{Rn} is geometric mean concentrations of Thoron (Bq/m3), 0.02 ; equilibrium factor, T; daily working time that is 8 hours (2920 h/y) and 16 hours (5840 h/y); 40 is conversion coefficients of Thoron concentration to the effective dose received (nSv/Bq.m3.h) and 10-6 is the conversion coefficients of nano-Sievert to mili-Sievert [23].

2.3. Statistical Analysis

The difference in indoor and outdoor air Radon concentration at four warehouses of Decorative stones of diurnal Radon concentrations was statistically analyzed by Pair sample test in SPSS16 software. (P value<0.05)was considered as significant level (α=5%).

III. Results

The mean concentration of indoor air Radon (Radon 222 and Thoron) is 74±37 Bq/m^3. The mean concentration of indoor air Radon (M±SD) in Decorative stones warehouse DSW1, DSW2, DSW3 and DSW4 is 16±3-124±22, 33±6-157±27, 11±4-64±11 and 31±5-184±32 Bq/m^3 (Table 1). The order of warehouses of Decorative stones given the mean of indoor air Radon concentration is DSW3>DSW1>DSW4>DSW2. Total mean of outdoor Radon air is 34±16 Bq/m^3. Radon concentration outdoor air in warehouses DSW1, DSW2, DSW3 and DSW4 is 33±6, 28.6±5, 35.6±9 and 39±9.7 Bq/m^3, respectively (Table 2). The mean of Radon concentration during the day at DSW1, DSW2, DSW3 and DSW4 warehouses are 44.5±8, 63±11, 19.5±4 and 53.83±9 Bq/m^3 and during the night is 100.5±18, 133.5±23, 49.33±9 and 124±22 Bq/m^3. The ratio of mean concentration of Radon during the night than the day in indoor air at DSW1, DSW2, DSW3 and DSW4 warehouses are 3, 4.75, 1.4 and 3.17, respectively. The highest and lowest ratio is related to the storage of DSW2 and DSW3, respectively. The mean indoor air Radon 222 of Decorative stones warehouse of DSW1, DSW2, DSW3 and DSW4 are 51.13, 56, 26.33 and 67.07 Bq/m^3 and also the mean indoor air Thoron is 21.37, 42.17, and 21.33 Bq/m^3.

Table 1. Mean concentrations of indoor air Radon at four Decorative stones of warehouses during 24 hours (Bq/m^3).

Time (hr)	DSW1[1]	DSW2	DSW3	DSW4
9	[2]29±5	52±9	11±4	54±9
11	16±3	33±6	16±3	45±8
13	40±7	60±11	26±5	31±5
15	44±8	40±7	28±5	89±16
17	66±12	87±15	16±3	57±10
19	72±13	106±19	20±4	47±8
21	88±15	123±22	46±8	76±13
23	96±18	131±23	46±8	126±22
1	102±18	139±24	62±11	121±21
3	117±21	145±25	64±11	173±30
5	124±22	157±27	49±9	184±32
7	76±13	106±19	29±5	64±11
M±SD (Day)	44.5±8	63±11	19.5±4	53.83±9
M±SD (Night)	100.5±18	133.5±23	49.33±9	124±22
M±SD[3]	72.50±34	98.25±43	34.42±18	88.92±51

Table 2. Mean Radon 222 and indoor and outdoor air Thoron at four Decorative stone of warehouses

	Step 1 (November, 2012)				Step 2 (December,2012)				Step 3(January, 2012)				Sum[4]			
	Indoor[5]		Outdoor[6]		Indoor		Outdoor		Indoor		Outdoor		Indoor		Outdoor	
Number	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn	Tn
DSW 1	45	18	11	2	55	23	25	4	53	23	41	16	51.13	21.37	25.6	7
DSW 2	54	40	26	6	57	42	16	11	57	45	19	8	56.00	42.17	20.3	8.3
DSW 3	25	9	31	4	29	8	24	6	26	8	29	13	26.33	7.93	28	7.6
DSW 4	67	15	19	6	65	34	13	5	69	15	56	18	67.07	21.33	29	9.6
M±SD7	48±18	20±14	22±9	5±2	51±16	27±15	20±6	7±3	51±18	23±16	36±16	14±4	50.1±17	23.2±14	25.8±18	8.2±14

Table 3. Total concentration of Radon 222 and Thoron indoor air and the effective dose received in staff of 4 Decorative stones of warehouses

	Concentration of Radon (Bq/m^3)			Effective Dose (mSv/y)		Effective Dose (mSv/y)		Work Time (h/d)	
			Sum of ^{222}Rn+ Tn	Work time 8hr		Work time 16hr		8	16
	^{222}Rn	Tn	^{222}Rn	^{222}Rn	Tn	^{222}Rn	Tn	^{222}Rn+Tn	^{222}Rn+ Tn
DSW 1	51.13	21.37	72±34	0.54	0.05	1.08	0.10	0.59	1.17
DSW 2	56.00	42.17	98±43	0.59	0.10	1.18	0.20	0.69	1.37
DSW 3	26.33	7.93	34±18	0.28	0.02	0.55	0.04	0.30	0.59
BCW4	67.07	21.33	88±51	0.71	0.05	1.41	0.10	0.75	1.51
M±SD	50.1±17	23.2±14.1	73±37	0.53±0.18	0.05±0.03	1.05±0.36	0.11±0.07	0.58±0.2	1.16±0.41

1 Mean ± Standard Error
2 Mean of 3 level
3 Mean ± Standard Deviation

The mean indoor air Radon 222 and Thoron of indoor air is 50.1±17 and 23.2±14 Bq/m^3 and the outdoor air is 25.8±18 and 8.2±14 Bq/m^3 (Table 2). Effective dose received by the staff caused by indoor air Radon in Decorative stone of warehouses is DSW1, DSW2, DSW3 and DSW4 in 8 working hours are 0.59, 0.69, 0.30 and 0.75 mSv/y as well as 16 working hours is 1.17, 1.37, 0.59 and 2.43 mSv/y. Effective dose received by staff from the Radon 222 and Thoron indoor air in 8 working hours is 0.53±0.18 and 0.05±0.03 mSv/y, respectively and in 16 working hours is 1.05±0.36 and 0.11±0.07 mSv/y. Generally, the mean effective dose from Radon staff at 8 and 16 hours are 0.58±0.2 and 1.16±0.41 mSv/y, respectively (Table 3). The order of Decorative stones of warehouse in terms of Radon effective dose received are DSW4>DSW2>DSW1> DSW3. The effective dose received from Radon and Thoron at 8 working hours are 0.53±0.18 and 0.05±0.03 mSv/y and in 16 working hours is 1.05±0.36 and 0.11±0.07 mSv/y, respective (Table 3).

IV. Discussion

The ratio of mean indoor air Radon concentration to EPA Standard in Decorative stones of warehouses in DSW1, DSW2, DSW3 and DSW4 is 48.9, 66.3, 23.3, and 60 % .[10] The mean concentration of indoor air Radon in all warehouses is lower than the EPA standard. Also, the ratio of mean indoor air Radon in all warehouses is lower than the EPA standard level (Figure 1). Also, the ratio of Radon concentration mean in indoor air to WHO (100 Bq/m3) standard in Decorative stones of warehouses in DSW1, DSW2, DSW3 and DSW4 is 72.5, 98.23, 34.4 and 88.9 % .[11] The mean of indoor air Radon concentration is also lower than the WHO standard level (Figure 1).

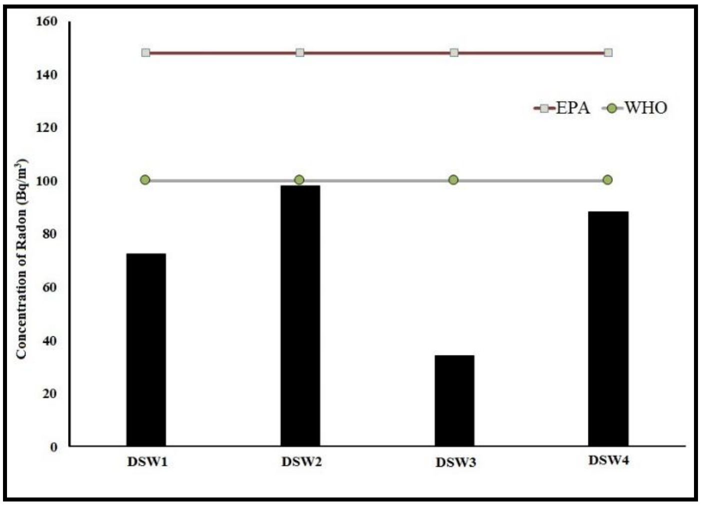

Figure 1. Comparing the mean concentration of indoor air Radon in 4 Decorative stone of warehouses (Radon 222 and Thoron) with the EPA and WHO standards.

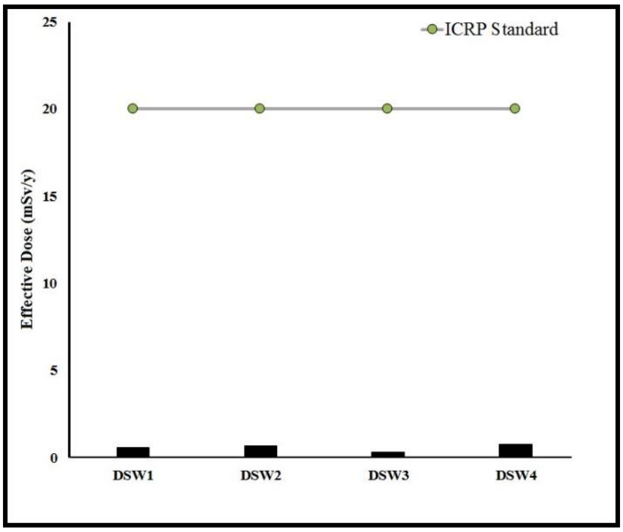

Figure 2. Comparing the effective dose received by staff with standard ICRP (8 hours).

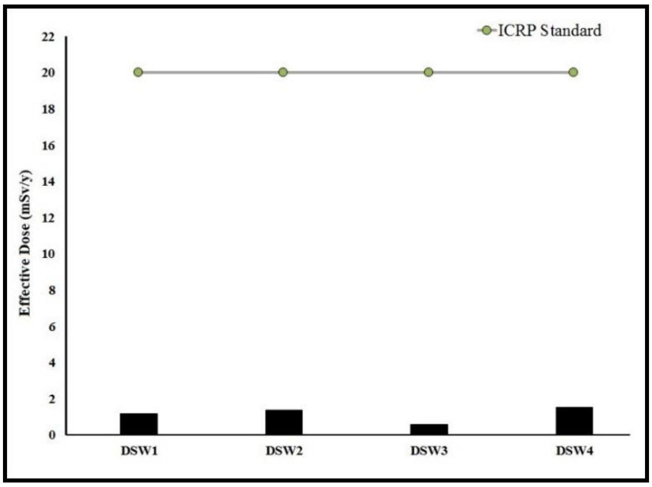

Figure 3. Comparing the effective dose received by staff with standard ICRP (16 hours).

The ratio of mean concentration of Radon indoor air to outdoor air in Decorative stones of warehouses in DSW1, DSW2, DSW3 and DSW4 is 2.22, 3.5, 0.95 and 2.29 times more than outdoor air. The maximum and minimum concentration of Radon indoor air to outdoor air is related to DSW2 and DSW3 warehouses, respectively. Mean concentrations of indoor air Radon in DSW1, DSW2 and DSW4 warehouses is more than outdoor air and in DSW3, it is less than outdoor air. Statistical analysis of Pair sample test showed that there is a significant difference between indoor and outdoor air Radon concentration in DSW1 (p value=0.027), DSW2(p value =0.014) and DSW4 (p value=0.031) warehouses (p value <0.05). But, there is no significant difference between indoor and outdoor Radon air concentrations in DSW3 (p value=0.19) warehouses. Generally, Pair sample test statistical analysis showed that there is a significant difference between indoor and outdoor air Radon concentrations in four warehouses of Decorative stones of warehouses (p value <0.05). Hence, it can be said that Decorative stone of warehouses can be a source of Radon, which this difference in indoor air Radon concentration in warehouses of Decorative stones can be caused by the difference in the air ventilation rate (Natural and artificial), the stones stored, the warehouse volume (air exchange), the substance of warehouse materials and the difference in the kind of stone (granite, marble, etc.) .[26-24] The low concentration of indoor air Radon than the outdoor air in DSW3 warehouse can be resulted from high air ventilation, the difference in the material of stones stored and body materials of warehouse building. Since natural and artificial ventilation at night is less than the day, thus the Radon concentration in indoor air is more than the day. P value <0.05 showed that Radon concentration in indoor air in the night is significantly higher than the day (n4=576). The mean effective dose received by staff in 8 (0.58 ± 0.2 mSv/y) and 16 hours (1.16±0.41 mSv/y) is lower than the ICRP standards for the staff (20mSv/y). The highest and lowest effective dose received by the staff relates to BCW3 and BCW4, respectively (Figure 2 and 3).

Since the effective dose increases with increasing exposure time, thus the effective dose received in 16 hours is twice more than 8 hours .[23] High Radon concentration of indoor air Radon in BCW4 warehouse than other warehouses can be resulted from less air ventilation, the difference in stones materials stored and or the difference in body building materials .[27 ,25 ,24] Hence, the impact of each of these variables can be studied separately or together in subsequent studies. The order of indoor air Radon concentration with the effective dose received in four warehouses under study is different, because Thoron concentration in BCW2 (42.17 Bq/m3) warehouse is more than BCW4 (21.33 Bq/m3). Hence, the effective dose received from Radon (Radon 222 and Thorn) in warehouse BCW4 is higher. Since the half-life of Thoron (56 seconds) is much lower than the Radon 222 (3.82 days), hence the contribution of Thoron in the effective dose received is also lower [15 ,14].

V. Conclusions

The mean Radon concentration in indoor air at Decorative stone of warehouses (155.4±27 Bq/ m^3) is lower than the standard WHO and EPA. Effective dose received by staff at 8 and 16 working hours is lower than the standard ICRP. Since in warehouses stones of Decorative, Thoron concentration allocates 31.7% of Radon concentration to itself, hence the effective dose received can be obtained more accurately by simultaneous measurement of Radon 222 concentration and Radon. Since the maintenance warehouses of Decorative stones is the sources of Radon gas emissions, hence it is recommended that with proper ventilation, reducing working time and other forms of corrective action, the effective dose received by the staff is reduced.

[4] Number one hours concentration of radon indoor air in 4 Decorative stones of warehouses (288 sample in day and 288 in night)

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