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# Seasonal variation measurements of indoor Radon concentrations in the city of Benghazi- Libya

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## Highlights

- Indoor radon concentrations were measured in selected locations in the city of Benghazi.
- Seasonal variation for the summer and winter seasons were studied.
- Exhalation rates and annual effective doses were also calculated.

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## ABSTRACT

Indoor concentrations of radioactive radon gas were determined experimentally in fifteen selected locations within the grounds of the University of Benghazi, Benghazi city-Libya. Detection and registration of radon gas were achieved by means of CR-39 plastic detectors (SSNTD) attached to stainless steel cups that contain the samples using the method known as can technique or sealed-cup technique. Forty-five samples within the fifteen selected locations were counted for ninety days interval in the summer season and repeated for the winter season. Radon concentrations were determined for three different sample types in each of the fifteen locations. The three samples are defined as a brick wall, ceramic flooring and marble ledge in the faculty of Science building. Results showed that radon concentrations for all sample types and in all locations were below the ICRP action level limits in both seasons and their magnitudes are seasonal dependent, with high radon concentrations attained in the winter season. Exhalation rates and annual effective doses from all samples were also calculated and showed the familiar linear relationship with radon concentration.

## 1. Introduction

Radon has many isotopes, radon 222 ( $^{222}\text{Rn}$ ) is the most prominent isotope ( $t_{1/2} = 3.8$  d) and result from the nuclear decay of Uranium and Thorium atoms. These parent nuclei atoms are naturally radioactive and found in the environment that human live in. Small amounts of these radioactive substances can be found in the materials that people use in their living places which render them to be a source of radioactive radon gas that permeate into the living space of dwellings and working sites and then find their way into the lungs of the inhabitants which increase the risk of lung cancer (ICRP, 1978). Statistical data showed that radon cancer cases make up about 40% of all cancer cases.

In light of these important facts, many researchers directed their effort in studying, measuring and reporting radon and its risks (Durani, 1993). The International Commission on Radiological Protection (ICRP) recommended that radon concentration values to be in the range 500-1500 Bqm<sup>-3</sup> and an action level value of 200-600 Bqm<sup>-3</sup> is set for both working sites and dwellings making them risk-free for both workers and inhabitants (ICRP-1993).

Experimental measurements of radon concentrations in indoor areas have been given worldwide attention and have been reported in the literature by various researchers in different countries naming few examples; Austria (Friedmann, 2002), Yemen (Khayrat *et al.*, 2003), Mexico (Espinosa *et al.*, 1999). A previous study has been conducted in some working places at the University of Benghazi campus, which determined the radon concentration during the summertime (Saad *et al.*, 2010). However, the current study concentrates on the measurement of radon concentration in the winter

season in the same working places and then try to establish whether there is a seasonal variation dependence or not. These studies and others will, hopefully, serve as the beginning of the national survey baseline of radon measurements in Libya.

## 2. Materials and Method

The measurement of radon concentration is carried out by the common method known as sealed-can technique (Saad *et al.*, 2010; Fleischer *et al.*, 1980; Abu-Jarad *et al.*, 1980; Somogyi *et al.*, 1984). A cup made of steel is placed on top of the sample and a plastic detector is fixed on the inside ceiling of the cup. The cup is then isolated from the surroundings by a sealant applied around its edges. The plastic detector used here is CR-39 solid state nuclear track detector (SSNTD) of size 1.5 cm×1.5 cm manufactured by Intersect Europe Co., Parma, Italy (Saad *et al.*, 2010).

Forty-five cups were prepared and placed in fifteen locations in the faculty of science building within the grounds of the University of Benghazi. Three cups were used in each location for a brick wall, ceramic floor and marble edge samples respectively. Locations were selected to include seven departments, three floors, offices, laboratories and teaching rooms. All detectors were labeled according to the above criteria.

The sealed cups were left for an exposure time of ninety days during the summer season in order to obtain good statistics and the process was identically repeated for the winter season. After the detectors in the cups were exposed to radon and its decay daughters, alpha particles emitted from the decay will form tracks in the detector material medium. The SSNTDs were then removed from

the cups and etched chemically in 6.25 M NaOH solution at  $70 \pm 1^\circ \text{C}$  for 8 hours to display and enlarge the latent alpha tracks.

The etched tracks on the detectors were counted manually using an optical microscope at 400x magnification (Saad et al., 2010). The area of one field of view was accordingly calculated by stage micrometer and the track density was calculated in terms of tracks per  $\text{cm}^2$ . The background track density was determined by processing a blank detector under the same etching condition. The background was then subtracted from the measured track density. In order to obtain a realistically good statistics of tracks, 100 fields of view were selected randomly on the detector surface. The track densities were then converted into radon concentration by applying the calibration factor for InterCast CR-39 detectors as  $0.239 \pm 0.008$  tracks  $\text{cm}^{-2}$  equal to 1 Bq  $\text{m}^{-3}$  of radon (Saad, 2008).

Thus, radon concentration levels were calculated from the observed track densities using this calibration factor of  $0.239 \pm 0.008$  tracks  $\text{cm}^{-2}/\text{Bq m}^{-3}$  (Saad, 2008). Radon exhalation rate ( $E_x$ ) and annual effective dose ( $E_p$ ) were estimated according to the following equations respectively (Saad et al., 2010):

$$E_x = \frac{\lambda_v V_r C_{Rn}}{S_r} \quad (1)$$

$C_{Rn}$  is radon concentration (Bq  $\text{m}^{-3}$ ),  $V_r$  is room volume ( $\text{m}^3$ ),  $\lambda_v$  is air exchange rate ( $\text{h}^{-1}$ ), and  $S_r$  is sample surface area.

$$E_x = \frac{A_0 \lambda V}{S} \quad (2)$$

Where  $A_0$  is radon concentration recorded by the detector from the sample in the emanation cup,  $\lambda$  is the activity of the sample ( $\text{h}^{-1}$ ),  $V$  is the volume of the emanation cup ( $0.423 \pm 10^{-3} \text{m}^3$ ), and  $S$  is the total surface area of the building material sample ( $0.385 \pm 10^{-2} \text{m}^2$ ).

The annual effective dose ( $E_p$ ) is given by:

$$E_p (\text{WLM/Y}) = \frac{8760 n F C_{Rn}}{170 \times 3700} \quad (3)$$

Where  $n$  is the fraction of time spent indoors,  $F$  is the equilibrium factor, 8760 is the number of hours per year, 3700 is the conversion factor from unit (Bq/ $\text{m}^3$ ) to working level (WL), and 170 is the number of hours per working month.  $n=0.8$  and  $F=0.42$  were used to calculate  $E_p$ . A conversion factor of  $6.3 \text{mSv/WLM}$  was used to estimate the effective dose from working level month (WLM) values (ICRP, 1987).

### 3. Results and Discussion

Comparisons of all the values of radon concentration, exhalation rate, and annual effective dose for the summer and winter seasons are shown in Table 1. Comparisons of minimum, maximum and average indoor radon concentration levels observed for all samples and for each sample type of brick wall, ceramic floor, and marble ledge are also shown in Table 2. The results in Table 2 showed that radon concentration levels for the winter season have clearly higher levels than the summer season across the board. Marble ledge samples produced the highest average radon concentration levels for both seasons, while ceramic floor samples produced the lowest average value in the summer season compared to a brick wall, which produced the lowest average value for the winter season. However, the average radon concentration levels for both seasons from sample types were all within the range of the internationally recommended ICRP action level value for working places ( $500\text{--}1500 \text{Bq m}^{-3}$ ).

Seasonal comparison of minimum, maximum and average indoor radon concentration levels observed for different locations are given in Table 3. The average radon concentration level from the first floor was the highest for the summer season, whereas in the winter season the highest average value was from the second floor.

The minimum, maximum and average values for the radon exhalation rate and the annual effective dose from the brick walls, ceramic flooring, and marble ledge samples are shown in Table 4. The

results showed that the average radon exhalation rates ranged from  $0.110\text{--}0.131 \text{Bq m}^{-2} \text{h}^{-1}$  for the summer season compared to the range of  $0.413\text{--}0.504 \text{Bq m}^{-2} \text{h}^{-1}$  in the winter season. For the estimation of the expected annual effective dose to be received by the workers in the university campus due to radon and its progeny, a conversion factor by which 1 Bq  $\text{m}^{-3}$  of radon corresponding to yearly effective dose equivalent of 0.05 mSv was used as recommended by the Commission of the European Communities (CEC). Using CEC recommended conversion factor, minimum, maximum and average annual effective doses were also compared for the summer and winter seasons as shown in Table 4. The average values of annual effective dose from all samples within all working places showed higher winter doses compared to summer doses as expected since it follows the familiar linear relationship with the level of radon concentration.

### 4. Conclusion

A Survey of radon gas levels was performed at the University of Benghazi campus. Results showed that the levels of concentration of radon gas of all selected working places were within the range of the ICRP action level limits in both seasons (summer and winter) and the levels of indoor radon concentrations are seasonal dependent, with higher radon levels found to be in the winter season, as expected. The higher winter concentration levels may be due to several factors among them are the lack of ventilation and weather parameters such as temperature and humidity, which may cause higher radon emanation during the winter season. The average exhalation rates and annual effective dose due to radon gas from all samples within all working places showed the familiar linear relationship with radon levels as expected. Based on the result of this survey of seasonal variation it is concluded that the campus is safe for its occupants because the construction materials used to build the campus buildings are not a source of hazardous levels of radiation.

Based on this study, this work can be extended to survey indoor radon levels in the city of Benghazi and other areas in Libya, which will contribute to the safety and protection of public health.

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**Table 1**

Radon Concentration ( $C_{Rn}$ ), Radon Exhalation Rate per unit area ( $E_k$ ) and Annual Effective Dose ( $E_p$ ) for the summer and winter seasons from the various sample locations within the university campus. Departments: P physics, C-chemistry, G-geology, B-botany, Z-zoology, S-statistics, A-administrative. Sample type: W brick wall, F ceramic floor, M marble edge, Floor level: I Ground Floor GF, II First Floor FF, III Second Floor SF. 1-14 stands for locations.

| Season     |             | Summer                        |                                            |                              | Winter                        |                                            |                              |
|------------|-------------|-------------------------------|--------------------------------------------|------------------------------|-------------------------------|--------------------------------------------|------------------------------|
| Sample No. | Sample Code | $C_{Rn}$ (Bqm <sup>-3</sup> ) | $E_k$ (Bqm <sup>-2</sup> h <sup>-1</sup> ) | $E_p$ (mSv y <sup>-1</sup> ) | $C_{Rn}$ (Bqm <sup>-3</sup> ) | $E_k$ (Bqm <sup>-2</sup> h <sup>-1</sup> ) | $E_p$ (mSv y <sup>-1</sup> ) |
| 1          | PWI1        | 192.8±6.5                     | 0.146±0.005                                | 9.6±0.3                      | 559.7±18.7                    | 0.424±0.014                                | 28.0±0.9                     |
| 2          | PFI1        | 118.2±4.0                     | 0.089±0.003                                | 5.9±0.2                      | -                             | -                                          | -                            |
| 3          | PMI1        | 166.2±5.6                     | 0.126±0.004                                | 8.3±0.3                      | 642.8±21.5                    | 0.486±0.016                                | 32.1±1.1                     |
| 4          | PWI2        | 119.5±4.0                     | 0.090±0.003                                | 6.0±0.2                      | 332.4±11.1                    | 0.252±0.008                                | 16.6±0.6                     |
| 5          | PFI2        | 94.8±3.2                      | 0.072±0.002                                | 4.7±0.2                      | -                             | -                                          | -                            |
| 6          | PMI2        | 279.2±9.3                     | 0.211±0.007                                | 14.0±0.5                     | 623.3±20.9                    | 0.472±0.016                                | 31.2±1.0                     |
| 7          | PWI3        | 163.6±5.5                     | 0.124±0.004                                | 8.2±0.3                      | 541.5±18.1                    | 0.410±0.014                                | 27.1±0.9                     |
| 8          | PFI3        | 233.7±7.8                     | 0.177±0.006                                | 11.7±0.4                     | -                             | -                                          | -                            |
| 9          | PMI3        | 126.0±4.2                     | 0.095±0.003                                | 6.3±0.2                      | 718.1±24.0                    | 0.543±0.018                                | 35.9±1.2                     |
| 10         | PWI4        | 254.5±8.5                     | 0.193±0.006                                | 12.7±0.4                     | 958.4±32.1                    | 0.725±0.024                                | 47.9±1.6                     |
| 11         | PFI4        | 162.3±5.4                     | 0.123±0.004                                | 8.1±0.3                      | -                             | -                                          | -                            |
| 12         | PMI4        | 207.8±7.0                     | 0.157±0.005                                | 10.4±0.3                     | 590.9±19.8                    | 0.447±0.015                                | 29.5±1.0                     |
| 13         | PWI5        | 133.8±4.5                     | 0.101±0.003                                | 6.7±0.2                      | -                             | -                                          | -                            |
| 14         | PFI5        | 87.0±2.9                      | 0.066±0.002                                | 4.4±0.1                      | 1196.0±40                     | 0.905±0.030                                | 59.8±2.0                     |
| 15         | PMI5        | 119.5±4.0                     | 0.090±0.003                                | 6.0±0.2                      | 720.7±24.1                    | 0.545±0.018                                | 36.0±1.2                     |
| 16         | PWII6       | 277.9±9.3                     | 0.210±0.007                                | 13.9±0.5                     | 489.6±16.4                    | 0.370±0.012                                | 24.5±0.8                     |
| 17         | PFI6        | 148.0±5.0                     | 0.112±0.004                                | 7.4±0.2                      | -                             | -                                          | -                            |
| 18         | PMII6       | 231.8±7.8                     | 0.175±0.006                                | 11.6±0.4                     | -                             | 0.175±0.006                                | 11.6±0.4                     |
| 19         | PWII7       | 142.8±4.8                     | 0.108±0.004                                | 7.1±0.2                      | 477.9±7.80                    | 0.362±0.012                                | 23.9±0.8                     |
| 20         | PFI7        | 127.3±4.3                     | 0.096±0.003                                | 6.4±0.2                      | -                             | -                                          | -                            |
| 21         | PMII7       | 221.4±7.4                     | 0.168±0.006                                | 11.1±0.4                     | 915.5±30.6                    | 0.693±0.023                                | 45.8±1.5                     |
| 22         | PWIII8      | 141.5±4.7                     | 0.107±0.004                                | 7.1±0.2                      | 1406.4±47.1                   | 1.064±0.036                                | 70.3±2.4                     |
| 23         | PFI8        | 106.5±3.6                     | 0.081±0.003                                | 5.3±0.2                      | 1109±37.1                     | 0.839±0.028                                | 55.5±1.9                     |
| 24         | PMIII8      | 113.0±3.8                     | 0.085±0.003                                | 5.6±0.2                      | 953.2±31.9                    | 0.721±0.024                                | 47.7±1.6                     |
| 25         | AWI9        | 129.9±4.3                     | 0.098±0.003                                | 6.5±0.2                      | 202.6±06.8                    | 0.153±0.005                                | 10.1±0.3                     |
| 26         | AFI9        | 105.2±3.5                     | 0.080±0.003                                | 5.3±0.2                      | 702.5±23.5                    | 0.532±0.018                                | 35.1±1.2                     |
| 27         | AMI9        | 110.4±3.7                     | 0.084±0.003                                | 5.5±0.2                      | 470.1±05.0                    | 0.356±0.120                                | 23.5±0.8                     |
| 28         | AWI10       | 153.2±5.1                     | 0.116±0.004                                | 7.7±0.3                      | -                             | -                                          | -                            |
| 29         | AFI10       | -                             | -                                          | -                            | -                             | -                                          | -                            |
| 30         | AMI10       | -                             | -                                          | -                            | -                             | -                                          | -                            |
| 31         | CWII11      | 219.5±7.3                     | 0.166±0.006                                | 11.0±0.4                     | 418.2±14.0                    | 0.316±0.011                                | 20.9±0.7                     |
| 32         | CFII11      | 171.4±5.7                     | 0.130±0.004                                | 8.6±0.3                      | 435.0±14.6                    | 0.329±0.011                                | 21.8±0.7                     |
| 33         | CMII11      | 171.4±5.7                     | 0.130±0.004                                | 8.6±0.3                      | 479.2±16.0                    | 0.363±0.012                                | 24.0±0.8                     |
| 34         | GWII12      | 139.0±4.7                     | 0.105±0.004                                | 6.9±0.2                      | 540.2±18.1                    | 0.409±0.014                                | 27.0±0.9                     |
| 35         | GFI12       | -                             | -                                          | -                            | 209.1±07.0                    | 0.158±0.005                                | 10.5±0.3                     |
| 36         | GMI12       | 298.7±10.0                    | 0.226±0.008                                | 14.9±0.5                     | -                             | -                                          | -                            |
| 37         | BWI13       | -                             | -                                          | -                            | 553.2±18.5                    | 0.419±0.014                                | 27.7±0.9                     |
| 38         | BFI13       | 275.3±9.2                     | 0.208±0.007                                | 13.8±0.5                     | 361.0±12.1                    | 0.273±0.009                                | 18.1±0.6                     |
| 39         | BMI13       | 140.2±4.7                     | 0.106±0.004                                | 7.0±0.2                      | 644.1±21.6                    | 0.487±0.016                                | 32.2±1.1                     |
| 40         | ZWII14      | 213.6±7.2                     | 0.162±0.005                                | 10.7±0.4                     | 270.1±09.0                    | 0.204±0.007                                | 13.5±0.5                     |
| 41         | ZFII14      | 146.7±4.9                     | 0.111±0.004                                | 7.3±0.2                      | 240.2±08.0                    | 0.182±0.006                                | 12.0±0.4                     |
| 42         | ZMII14      | 146.7±4.9                     | 0.111±0.004                                | 7.3±0.2                      | -                             | -                                          | -                            |
| 43         | SWI15       | 107.8±3.6                     | 0.082±0.003                                | 5.4±0.2                      | 346.7±11.6                    | 0.262±0.009                                | 17.3±0.6                     |
| 44         | SFI15       | 110.4±3.7                     | 0.084±0.003                                | 5.5±0.2                      | 406.5±13.6                    | 0.308±0.010                                | 20.3±0.7                     |
| 45         | SMI15       | 100.0±3.3                     | 0.076±0.003                                | 5.0±0.2                      | 568.8±19.0                    | 0.430±0.014                                | 28.4±1.0                     |

**Table 2**

Comparison of radon concentrations ( $\text{Bqm}^{-3}$ ) for different sample types in summer and winter seasons.

| Concentration parameter | Summer season |               |            |             | Winter season |               |            |             |
|-------------------------|---------------|---------------|------------|-------------|---------------|---------------|------------|-------------|
|                         | All samples   | Ceramic Floor | Brick Wall | Marble Edge | All samples   | Ceramic Floor | Brick Wall | Marble Edge |
| minimum                 | 87            | 87            | 107.8      | 100         | 202.6         | 209.1         | 202.6      | 470.1       |
| maximum                 | 298.7         | 275.3         | 277.9      | 298.7       | 1406.4        | 1196          | 1406.4     | 953.2       |
| average                 | 163.6         | 145.1         | 170.7      | 173.7       | 596.3         | 582.4         | 545.9      | 666.1       |

**Table3**

Comparison of radon concentrations ( $\text{Bqm}^{-3}$ ) for different samples according to the location of samples in summer and winter seasons

| Concentration parameter | Summer season |             |              | Winter season |             |              |
|-------------------------|---------------|-------------|--------------|---------------|-------------|--------------|
|                         | Ground Floor  | First Floor | Second Floor | Ground Floor  | First Floor | Second Floor |
| minimum                 | 87            | 127.3       | 106.5        | 202.6         | 209.1       | 953.2        |
| maximum                 | 279.2         | 298.7       | 141.5        | 1196          | 915.5       | 1406.4       |
| average                 | 153.8         | 187.3       | 120.3        | 586.3         | 447.5       | 1156.2       |

**Table4**

Comparison of Radon exhalations rates and annual effective doses for different samples in summer and winter seasons.

| parameter                                                        |         | Summer season |       |       |             | Winter season |       |       |             |
|------------------------------------------------------------------|---------|---------------|-------|-------|-------------|---------------|-------|-------|-------------|
|                                                                  |         | All Samples   | Floor | Wall  | Marble Edge | All samples   | Floor | Wall  | Marble Edge |
| Exhalation Rate per unit area ( $\text{Bqm}^{-2}\text{h}^{-1}$ ) | minimum | 0.066         | 0.066 | 0.082 | 0.076       | 0.153         | 0.158 | 0.153 | 0.356       |
|                                                                  | maximum | 0.226         | 0.208 | 0.193 | 0.226       | 1.064         | 0.905 | 1.064 | 0.721       |
|                                                                  | average | 0.123         | 0.11  | 0.129 | 0.131       | 0.451         | 0.441 | 0.413 | 0.504       |
| Annual Effective Dose ( $\text{mSv y}^{-1}$ )                    | minimum | 4.4           | 4.4   | 5.4   | 5           | 10.1          | 10.5  | 10.1  | 23.5        |
|                                                                  | maximum | 14.9          | 13.8  | 13.9  | 14.9        | 70.3          | 59.8  | 70.3  | 47.7        |
|                                                                  | average | 8.2           | 7.3   | 8.5   | 8.7         | 29.8          | 29.1  | 27.3  | 33.3        |