Indoor radon measurements in Erzurum province of Turkey

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Abstract. Indoor radon measurements were carried out in dwellings in Erzurum province during the winter months of February 2012 to early April 2012 and the summer months of July 2012 to early September 2012. Nuclear track detector LR-115 was used for the measurements. According to the results of investigations, it was understood that the indoor radon concentration averages in dwellings are in the range of $11 \pm 6$ $\text{Bq m}^{-3}$ to $356 \pm 64$ $\text{Bq m}^{-3}$ in summer season. We found that the $^{222}\text{Rn}$ effective dose values in the studied dwellings in winter season range from 0.278 to 9.59 mSv y$^{-1}$. Also, the $^{222}\text{Rn}$ effective dose values in the studied dwellings in summer season range from 0.202 to 8.98 mSv y$^{-1}$. These values are within the ICPR recommended values. The radon activity has not been found to vary with seasonal changes, but also with the age, the construction mode of houses, the ventilation conditions and with specific sites and geological materials.

1. Introduction

The increasing awareness concerning radon ($^{222}\text{Rn}$) health hazards on organic structures obligates researchers to investigate the sources and impacts within the environment. There is a direct correlation between radon exposure and some types of cancer. The risk of lung cancer from the inhalation of radon is the most significant health hazards. Radon is a radioactive gas produced by the radioactive decay of uranium and thorium. The detection of indoor radon levels is extremely difficult. It is a colorless, odorless, tasteless gas detectable by utilizing special equipment. The main natural sources of indoor radon are the soil gas, building materials, tap water and natural gas used for cooking. Also, a number of anthropogenic activities (mining operations, the use of phosphate fertilizers, burning of fossil fuels) has increased the radon exposure to general public.

It is necessary to monitor radon. Therefore, both active and passive techniques have been developed. Active methods are usually used for short term measurements of radon and for detailed investigations of individual sites under inspection. Passive methods are more suitable for the assessment of radon exposure over long time scales and can be used for large scale surveys at moderate cost. For that reason, many countries have performed large-scale radon surveys using passive monitoring devices, which helps to assess the public exposure, and adopted appropriate actions for protection against radon. In this work, LR-115 nuclear track detector was used for large-scale surveys of environmental radon.

There has been an increasing interest in the measurement of indoor radon concentration levels throughout the world. The International Commission on Radiological Protection (ICRP), with over a hundred publications devoted to radon studies, gives both human and environmental recommendations for radiological protection. Further, they have researched and identified geographic areas, where houses are likely to have high radon risk and should therefore be considered as radon prone.

Recently several studies underscore the attention and severity of radon concerns. For example: Concentration of radioactive radon gas ($^{222}\text{Rn}$) were measured using passive monitors based on LR115 solid state track detectors during June-July 2010 indoor air of dwelling in the Nui Beo coal mining area, mostly in Cam Pha and Ha Long coastal towns (Nhan et al., 2012). In a study, Indoor radon measurements were carried out in elementary schools in Tunis, the capital city of Tunisia, during the winter months of December 2008 to early March 2009. Two classrooms, one each from ground floor and first floor were chosen from each school making a total of 60 classrooms. Nuclear
track detector type LR-115 (Kodalpha) was used for the measurements (Labidi et al., 2010). In another work, radon / thoron and their progeny concentrations were measured in different types of dwellings at different locations around industrial areas, cities and rural areas of Brahmaputra Valley of Assam by using LR-115(type- II) plastic detector. Radon levels of different dwellings were analysed with reference to the nature building materials, ventilation patterns and the types of underlying soil. The results were discussed under the light of exposure limits set by ICPR (Deka et al., 2003).

In addition, radon ($^{222}$Rn) and thoron ($^{220}$Rn) $\alpha$ activities per unit volume were measured inside and outside different building materials by using two types of solid state nuclear track detectors (SSNTD) (CR-39 and LR-115 type II). The radon and thoron emanation coefficients of the studied materials were evaluated (Misdaq et al., 2000). Furthermore, the results of radon activity recorded in 70 dwellings of Nurpur area in India are reported. LR -115 type II films in bare mode were exposed for four seasons of three months each covering a period of one year for the measurement of indoor radon levels (Singh et al., 2004). Indoor radon measurement survey has been carried out in properly selected houses of the city of Islamabad (Rahman et al., 2008). The indoor radon activity level and radon effective dose rate were carried out in Moroccan dwellings using SSNTDs (Oufni et al, 2005).

Figure 1. Map showing the studied area of Erzurum Province in Turkey.

Therefore, we want to recognize the importance of the accurate evaluation of radon concentration and exposure. Although Turkey has conducted Radon surveys, the city of Erzurum has not. Therefore this area is the target of our study to assess any health risk from radon. Erzurum is a city in eastern Turkey. The city is found with 39º 54' 35'' N, 41º 16' 32''E coordinates (see Fig 1.) Erzurum has a continental climate. Summer is brief, but summer days are warm, though with cool nights. Winters are very cold and long, with an average minimum during January of around -16 °C (3 °F); temperatures fall below -30 °C (-22 °F) most years.

2. Material and method

Measurements over several months are better than short-term measurements for estimating annual average radon levels. The plastic track etch detectors are the most common method to measure radon. For this reason, the indoor radon activity concentrations were measured by LR-115 nuclear track detectors.
A total of 110 of these units were placed in houses at center of Erzurum city and extending to the surrounding areas. Rooms that are rarely used were avoided to accurately reflect people’s true exposure to radon. Therefore, detectors were placed in rooms where people spend most of the time such as living room and bedrooms. Average exposure time of LR-115 detectors was 60 days. Detectors were placed in the selected houses, at least 1m from the floor and away from doors or windows. LR-115 type II detectors are given in Fig.2. LR -115 is a commercial name of cellulose nitrate (C$_6$H$_2$O$_9$N$_2$) detector made by Kodak-Path, France. After an exposure time of 2 months, detector films were removed and etched in a NaOH solution (2.5 N at 60 ºC during 100 min for LR-115 type II films) in a constant temperature bath. Then these SSNTDs were washed, dried and scanned under a binocular microscope for track density measurements. LR -115 has an active layer of 12 µm red-dyed cellulose nitrate film coated on inert polyester base of 100 µm thickness. The thickness of 12 µm is designed for spark counting of α- particle tracks recorded in the film. LR-115 is welcomed by scientist for the reason that α- particles emitted from radon progenies attached onto the surface of detector cannot developed by chemical etching for short etching times. The energies of the α-particles from the short-lived progenies are all higher than 6.0 MeV, which are beyond the energy window 0.06-6 MeV of LR-115. In contrast, all the α- particles from the progenies can form etchable tracks in CR-39 by a short etching time. This is an advantage of LR-115 over CR-39 (L’Annunziata, 2003).

3. Results and discussions
In the present investigations, the indoor $^{222}$Rn concentration has been studied in 110 dwelling of Erzurum. The houses were chosen randomly in such a way that the dwellings constructed with different types of building materials such as brick, cement, and concrete. Indoor radon concentration levels have been determined for ground floor and first floor since floor level significantly affects the radon concentration. Radon levels vary significantly between seasons, so the measurements for indoor radon concentration levels were carried out during the winter months of February 2012 to early April 2012 and the summer months of July 2012 to early September 2012. The results of these measurements are shown in Table 1 and Table 2. The value of standard deviations is also given in Table1 and 2.
Table 1. The results of the radon concentration measurements with the value of standard deviations in winter.

| Detector Number | Starting date | Ending date | No. days | Exposure kBq.h/m³ | Avg. radon conc. Bq/m³ | Uncertainty 2 σ ± % ± Bq/m³ |
|-----------------|---------------|-------------|----------|-------------------|------------------------|-----------------------------|
| 384267          | 16.02.12      | 16.04.12    | 60.0     | 28                | 19                     | 46% 9                      |
| 384248          | 16.02.12      | 16.04.12    | 60.0     | 35                | 24                     | 44% 11                     |
| 384160          | 11.02.12      | 11.04.12    | 60.0     | 34                | 24                     | 44% 11                     |
| 384156          | 11.02.12      | 11.04.12    | 60.0     | 25                | 17                     | 48% 8                      |
| 384162          | 11.02.12      | 11.04.12    | 60.0     | 14                | 10                     | 56% 6                      |
| 384161          | 11.02.12      | 11.04.12    | 60.0     | 29                | 20                     | 46% 9                      |
| 384245          | 16.02.12      | 16.04.12    | 60.0     | 27                | 19                     | 47% 9                      |
| 384155          | 11.02.12      | 11.04.12    | 60.0     | 56                | 39                     | 38% 15                     |
| 384166          | 11.02.12      | 11.04.12    | 60.0     | 55                | 38                     | 39% 15                     |
| 384167          | 11.02.12      | 11.04.12    | 60.0     | 23                | 16                     | 49% 8                      |
| 384168          | 11.02.12      | 11.04.12    | 60.0     | 111               | 77                     | 32% 25                     |
| 384165          | 11.02.12      | 11.04.12    | 60.0     | 30                | 21                     | 45% 9                      |
| 384169          | 11.02.12      | 11.04.12    | 60.0     | 36                | 25                     | 43% 11                     |
| 384150          | 11.02.12      | 11.04.12    | 60.0     | 18                | 12                     | 53% 6                      |
| 384152          | 11.02.12      | 11.04.12    | 60.0     | 16                | 11                     | 54% 6                      |
| 384151          | 11.02.12      | 11.04.12    | 60.0     | 31                | 22                     | 45% 10                     |
| 384163          | 11.02.12      | 11.04.12    | 60.0     | 39                | 27                     | 42% 11                     |
| 384220          | 15.02.12      | 15.04.12    | 60.0     | 50                | 35                     | 39% 14                     |
| 384222          | 15.02.12      | 15.04.12    | 60.0     | 46                | 32                     | 40% 13                     |
| 384229          | 15.02.12      | 15.04.12    | 60.0     | 44                | 31                     | 41% 13                     |
| 384230          | 15.02.12      | 15.04.12    | 60.0     | 28                | 19                     | 46% 9                      |
| 384231          | 15.02.12      | 15.04.12    | 60.0     | 62                | 43                     | 37% 16                     |
| 384232          | 15.02.12      | 15.04.12    | 60.0     | 27                | 19                     | 47% 9                      |
| 384233          | 15.02.12      | 15.04.12    | 60.0     | 37                | 26                     | 43% 11                     |
| 384223          | 15.02.12      | 15.04.12    | 60.0     | 47                | 33                     | 40% 13                     |
| 384224          | 15.02.12      | 15.04.12    | 60.0     | 114               | 79                     | 32% 25                     |
| 384226          | 15.02.12      | 15.04.12    | 60.0     | 292               | 203                    | 26% 53                     |
| 384227          | 15.02.12      | 15.04.12    | 60.0     | 157               | 109                    | 30% 33                     |
| 384228          | 15.02.12      | 15.04.12    | 60.0     | 130               | 90                     | 31% 28                     |
| 384234          | 15.02.12      | 15.04.12    | 60.0     | 60                | 41                     | 38% 16                     |
| 384221          | 15.02.12      | 15.04.12    | 60.0     | 49                | 34                     | 40% 14                     |
| 384157          | 11.02.12      | 11.04.12    | 60.0     | 38                | 27                     | 42% 11                     |
| 384158          | 11.02.12      | 11.04.12    | 60.0     | 30                | 21                     | 45% 9                      |
| 384154          | 11.02.12      | 11.04.12    | 60.0     | 22                | 15                     | 50% 8                      |
| 384202          | 14.02.12      | 14.04.12    | 60.0     | 16                | 11                     | 54% 6                      |
| 384201          | 14.02.12      | 14.04.12    | 60.0     | 50                | 34                     | 40% 14                     |
| 384178          | 14.02.12      | 14.04.12    | 60.0     | 330               | 229                    | 26% 60                     |
| 384179          | 14.02.12      | 14.04.12    | 60.0     | 103               | 72                     | 33% 24                     |
| 384203          | 14.02.12      | 14.04.12    | 60.0     | 274               | 190                    | 27% 51                     |
| 384204          | 14.02.12      | 14.04.12    | 60.0     | 391               | 271                    | 25% 68                     |
| 384239          | 15.02.12      | 15.04.12    | 60.0     | 60                | 42                     | 38% 16                     |
| 384238          | 15.02.12      | 15.04.12    | 60.0     | 24                | 17                     | 48% 8                      |
| 384237          | 15.02.12      | 15.04.12    | 60.0     | 58                | 40                     | 38% 15                     |
| 384236          | 15.02.12      | 15.04.12    | 60.0     | 68                | 47                     | 36% 17                     |
| 384235          | 15.02.12      | 15.04.12    | 60.0     | 136               | 95                     | 31% 29                     |
| 384205          | 14.02.12      | 14.04.12    | 60.0     | 88                | 61                     | 34% 21                     |
### Table 1. Continued.

|   | 14.02.12 | 14.04.12 | 60.0 | 30 | 21 | 46% | 10 |
|---|----------|----------|------|----|----|-----|----|
| 384206 | 13.02.12 | 13.04.12 | 60.0 | 71 | 50 | 36% | 18 |
| 384217 | 13.02.12 | 13.04.12 | 60.0 | 22 | 16 | 49% | 8  |
| 384214 | 13.02.12 | 13.04.12 | 60.0 | 85 | 59 | 34% | 20 |
| 384216 | 13.02.12 | 13.04.12 | 60.0 | 42 | 29 | 42% | 12 |
| 384217 | 13.02.12 | 13.04.12 | 60.0 | 30 | 21 | 45% | 9  |
| 384209 | 14.02.12 | 14.04.12 | 60.0 | 44 | 31 | 41% | 13 |
| 384208 | 14.02.12 | 14.04.12 | 60.0 | 24 | 17 | 48% | 8  |
| 384207 | 14.02.12 | 14.04.12 | 60.0 | 22 | 16 | 49% | 8  |
| 384213 | 13.02.12 | 13.04.12 | 60.0 | 279 | 194 | 27% | 52 |
| 384215 | 13.02.12 | 13.04.12 | 60.0 | 47 | 33 | 40% | 13 |
| 384254 | 16.02.12 | 16.04.12 | 60.0 | 251 | 174 | 27% | 47 |
| 384255 | 16.02.12 | 16.04.12 | 60.0 | 25 | 17 | 48% | 8  |
| 384256 | 16.02.12 | 16.04.12 | 60.0 | 42 | 29 | 42% | 12 |
| 384257 | 16.02.12 | 16.04.12 | 60.0 | 86 | 60 | 34% | 20 |
| 384258 | 16.02.12 | 16.04.12 | 60.0 | 344 | 239 | 26% | 62 |
| 384259 | 16.02.12 | 16.04.12 | 60.0 | 233 | 162 | 28% | 45 |
| 384249 | 16.02.12 | 16.04.12 | 60.0 | 63 | 44 | 37% | 16 |
| 384250 | 16.02.12 | 16.04.12 | 60.0 | 58 | 40 | 38% | 15 |
| 384251 | 16.02.12 | 16.04.12 | 60.0 | 32 | 23 | 44% | 10 |
| 384252 | 16.02.12 | 16.04.12 | 60.0 | 87 | 61 | 34% | 21 |
| 384253 | 16.02.12 | 16.04.12 | 60.0 | 25 | 17 | 48% | 8  |
| 384260 | 17.02.12 | 17.04.12 | 60.0 | 167 | 116 | 30% | 35 |
| 384261 | 17.02.12 | 17.04.12 | 60.0 | 444 | 309 | 25% | 77 |
| 384262 | 17.02.12 | 17.04.12 | 60.0 | 124 | 86 | 32% | 28 |
| 384263 | 17.02.12 | 17.04.12 | 60.0 | 183 | 127 | 29% | 37 |
| 384264 | 17.02.12 | 17.04.12 | 60.0 | 216 | 150 | 28% | 42 |
| 384265 | 17.02.12 | 17.04.12 | 60.0 | 241 | 168 | 27% | 45 |
| 384266 | 17.02.12 | 17.04.12 | 60.0 | 38 | 26 | 43% | 11 |
| 384268 | 17.02.12 | 17.04.12 | 60.0 | 32 | 22 | 45% | 10 |
| 384259 | 12.02.12 | 12.04.12 | 60.0 | 172 | 119 | 29% | 35 |
| 384250 | 12.02.12 | 12.04.12 | 60.0 | 29 | 20 | 46% | 9  |
| 384258 | 12.02.12 | 12.04.12 | 60.0 | 51 | 35 | 39% | 14 |
| 384219 | 12.02.12 | 12.04.12 | 60.0 | 25 | 17 | 48% | 8  |
| 384211 | 12.02.12 | 12.04.12 | 60.0 | 34 | 24 | 44% | 11 |
| 384212 | 12.02.12 | 12.04.12 | 60.0 | 32 | 22 | 45% | 10 |
| 384214 | 12.02.12 | 12.04.12 | 60.0 | 25 | 17 | 48% | 8  |
| 384213 | 12.02.12 | 12.04.12 | 60.0 | 22 | 15 | 50% | 8  |
| 384218 | 12.02.12 | 12.04.12 | 60.0 | 30 | 21 | 46% | 10 |
| 384217 | 13.02.12 | 13.04.12 | 60.0 | 36 | 25 | 43% | 11 |
| 384254 | 13.02.12 | 13.04.12 | 60.0 | 110 | 77 | 32% | 25 |
| 384255 | 13.02.12 | 13.04.12 | 60.0 | 45 | 31 | 41% | 13 |
| 384256 | 13.02.12 | 13.04.12 | 60.0 | 69 | 48 | 36% | 17 |
| 384257 | 13.02.12 | 13.04.12 | 60.0 | 41 | 28 | 42% | 12 |
| 384258 | 13.02.12 | 13.04.12 | 60.0 | 28 | 19 | 46% | 9  |
| 384259 | 13.02.12 | 13.04.12 | 60.0 | 28 | 19 | 46% | 9  |
| 384260 | 16.02.12 | 16.04.12 | 60.0 | 32 | 22 | 45% | 10 |
| 384261 | 16.02.12 | 16.04.12 | 60.0 | 43 | 30 | 41% | 12 |
| 384262 | 13.02.12 | 13.04.12 | 60.0 | 49 | 34 | 40% | 14 |
### Table 1. Continued.

| Detector Number | Starting date | Ending date | No. days | Exposure kBq.h/m³ | Avg. radon conc. Bq/m³ | Uncertainty 2σ ± % | Uncertainty 2σ ± Bq/m³ |
|----------------|---------------|-------------|----------|------------------|------------------------|---------------------|-------------------------|
| 384195         | 13.02.12      | 13.04.12    | 60.0     | 49               | 34                     | 40%                 | 14                      |
| 384196         | 13.02.12      | 13.04.12    | 60.0     | 548              | 380                    | 24%                 | 91                      |
| 384197         | 13.02.12      | 13.04.12    | 60.0     | 84               | 58                     | 35%                 | 20                      |
| 384210         | 14.02.12      | 14.04.12    | 60.0     | 77               | 53                     | 35%                 | 19                      |
| 384211         | 14.02.12      | 14.04.12    | 60.0     | 37               | 26                     | 43%                 | 11                      |
| 384212         | 14.02.12      | 14.04.12    | 60.0     | 81               | 56                     | 35%                 | 20                      |
| 384213         | 14.02.12      | 14.04.12    | 60.0     | 62               | 43                     | 37%                 | 16                      |
| 384215         | 14.02.12      | 14.04.12    | 60.0     | 29               | 20                     | 46%                 | 9                       |
| 384214         | 14.02.12      | 14.04.12    | 60.0     | 39               | 27                     | 42%                 | 11                      |
| 384216         | 14.02.12      | 14.04.12    | 60.0     | 38               | 27                     | 42%                 | 11                      |

### Table 2. The results of the radon concentration measurements with the value of standard deviations in summer.

| Detector Number | Starting date | Ending date | No. days | Exposure kBq.h/m³ | Avg. radon conc. Bq/m³ | Uncertainty 2σ ± % | Uncertainty 2σ ± Bq/m³ |
|----------------|---------------|-------------|----------|------------------|------------------------|---------------------|-------------------------|
| 384270         | 12.07.12      | 12.09.12    | 62,0     | 27               | 18                     | 31%                 | 6                       |
| 384271         | 12.07.12      | 12.09.12    | 62,0     | 29               | 19                     | 31%                 | 6                       |
| 384272         | 12.07.12      | 12.09.12    | 62,0     | 36               | 24                     | 29%                 | 7                       |
| 384273         | 12.07.12      | 12.09.12    | 62,0     | 143              | 96                     | 21%                 | 20                      |
| 384274         | 12.07.12      | 12.09.12    | 62,0     | 19               | 13                     | 34%                 | 4                       |
| 384275         | 12.07.12      | 12.09.12    | 62,0     | 25               | 17                     | 32%                 | 5                       |
| 384276         | 12.07.12      | 12.09.12    | 62,0     | 25               | 17                     | 32%                 | 5                       |
| 384277         | 12.07.12      | 12.09.12    | 62,0     | 22               | 15                     | 33%                 | 5                       |
| 384278         | 12.07.12      | 12.09.12    | 62,0     | 48               | 32                     | 27%                 | 9                       |
| 384279         | 12.07.12      | 12.09.12    | 62,0     | 28               | 19                     | 31%                 | 6                       |
| 384280         | 12.07.12      | 12.09.12    | 62,0     | 196              | 132                    | 20%                 | 26                      |
| 384281         | 12.07.12      | 12.09.12    | 62,0     | 18               | 12                     | 34%                 | 4                       |
| 384282         | 12.07.12      | 12.09.12    | 62,0     | 17               | 11                     | 35%                 | 4                       |
| 384283         | 12.07.12      | 12.09.12    | 62,0     | 42               | 29                     | 28%                 | 8                       |
| 384284         | 12.07.12      | 12.09.12    | 62,0     | 53               | 36                     | 26%                 | 9                       |
| 384285         | 12.07.12      | 12.09.12    | 62,0     | 36               | 24                     | 29%                 | 7                       |
| 384286         | 12.07.12      | 12.09.12    | 62,0     | 65               | 43                     | 25%                 | 11                      |
| 384287         | 12.07.12      | 12.09.12    | 62,0     | 62               | 41                     | 25%                 | 10                      |
| 384288         | 12.07.12      | 12.09.12    | 62,0     | 36               | 24                     | 29%                 | 7                       |
| 384289         | 12.07.12      | 12.09.12    | 62,0     | 28               | 19                     | 31%                 | 6                       |
| 384290         | 12.07.12      | 12.09.12    | 62,0     | 91               | 61                     | 23%                 | 14                      |
| 384291         | 12.07.12      | 12.09.12    | 62,0     | 71               | 48                     | 24%                 | 12                      |
| 384292         | 12.07.12      | 12.09.12    | 62,0     | 24               | 16                     | 32%                 | 5                       |
| 384293         | 12.07.12      | 12.09.12    | 62,0     | 73               | 49                     | 24%                 | 12                      |
| 384294         | 12.07.12      | 12.09.12    | 62,0     | 150              | 100                    | 21%                 | 21                      |
| 384295         | 12.07.12      | 12.09.12    | 62,0     | 23               | 16                     | 32%                 | 5                       |
| 384296         | 12.07.12      | 12.09.12    | 62,0     | 64               | 43                     | 25%                 | 11                      |
| 384297         | 12.07.12      | 12.09.12    | 62,0     | 13               | 9                      | 38%                 | 3                       |
| 384298         | 12.07.12      | 12.09.12    | 62,0     | 44               | 30                     | 27%                 | 8                       |
| 384299         | 12.07.12      | 12.09.12    | 62,0     | 33               | 22                     | 30%                 | 7                       |
| 384300         | 12.07.12      | 12.09.12    | 62,0     | 14               | 10                     | 37%                 | 4                       |
Table 2. Continued.

|     | 12.07.12 | 12.09.12 | 62.0 | 13 | 9 | 38% | 3 |
|-----|-----------|-----------|------|----|---|-----|---|
| 384287 | 12.07.12 | 12.09.12 | 62.0 | 62 | 41 | 25% | 10 |
| 384291 | 12.07.12 | 12.09.12 | 62.0 | 241 | 162 | 19% | 31 |
| 384289 | 12.07.12 | 12.09.12 | 62.0 | 168 | 113 | 20% | 23 |
| 384290 | 12.07.12 | 12.09.12 | 62.0 | 530 | 356 | 18% | 64 |
| 384327 | 13.07.12 | 13.09.12 | 62.0 | 29 | 19 | 31% | 6 |
| 384325 | 13.07.12 | 13.09.12 | 62.0 | 17 | 11 | 35% | 4 |
| 384319 | 13.07.12 | 13.09.12 | 62.0 | 52 | 35 | 26% | 9 |
| 384330 | 13.07.12 | 13.09.12 | 62.0 | 36 | 24 | 29% | 7 |
| 384321 | 13.07.12 | 13.09.12 | 62.0 | 41 | 27 | 28% | 8 |
| 384317 | 13.07.12 | 13.09.12 | 62.0 | 295 | 199 | 19% | 38 |
| 384316 | 13.07.12 | 13.09.12 | 62.0 | 22 | 15 | 33% | 5 |
| 384324 | 13.07.12 | 13.09.12 | 62.0 | 18 | 12 | 34% | 4 |
| 384322 | 13.07.12 | 13.09.12 | 62.0 | 120 | 81 | 22% | 18 |
| 384315 | 13.07.12 | 13.09.12 | 62.0 | 25 | 17 | 32% | 5 |
| 384314 | 13.07.12 | 13.09.12 | 62.0 | 14 | 10 | 37% | 4 |
| 384329 | 13.07.12 | 13.09.12 | 62.0 | 17 | 11 | 35% | 4 |
| 384320 | 13.07.12 | 13.09.12 | 62.0 | 106 | 71 | 22% | 16 |
| 384348 | 13.07.12 | 13.09.12 | 62.0 | 41 | 27 | 28% | 8 |
| 384346 | 13.07.12 | 13.09.12 | 62.0 | 21 | 14 | 33% | 5 |
| 384347 | 13.07.12 | 13.09.12 | 62.0 | 57 | 38 | 26% | 10 |
| 384345 | 13.07.12 | 13.09.12 | 62.0 | 453 | 304 | 18% | 55 |
| 384341 | 13.07.12 | 13.09.12 | 62.0 | 28 | 19 | 31% | 6 |
| 384343 | 13.07.12 | 13.09.12 | 62.0 | 42 | 29 | 28% | 8 |
| 384344 | 13.07.12 | 13.09.12 | 62.0 | 23 | 15 | 33% | 5 |
| 384342 | 13.07.12 | 13.09.12 | 62.0 | 182 | 122 | 20% | 24 |
| 384359 | 13.07.12 | 13.09.12 | 62.0 | 43 | 29 | 27% | 8 |
| 384333 | 13.07.12 | 13.09.12 | 62.0 | 92 | 62 | 23% | 14 |
| 384334 | 13.07.12 | 13.09.12 | 62.0 | 103 | 69 | 22% | 15 |
| 384335 | 13.07.12 | 13.09.12 | 62.0 | 222 | 149 | 20% | 30 |
| 384332 | 13.07.12 | 13.09.12 | 62.0 | 62 | 41 | 25% | 10 |
| 384336 | 13.07.12 | 13.09.12 | 62.0 | 225 | 151 | 20% | 30 |
| 384337 | 13.07.12 | 13.09.12 | 62.0 | 63 | 43 | 25% | 11 |
| 384338 | 13.07.12 | 13.09.12 | 62.0 | 73 | 49 | 24% | 12 |
| 384339 | 13.07.12 | 13.09.12 | 62.0 | 73 | 49 | 24% | 12 |
| 384369 | 14.07.12 | 14.09.12 | 62.0 | 81 | 54 | 24% | 13 |
| 384368 | 14.07.12 | 14.09.12 | 62.0 | 54 | 36 | 26% | 9 |
| 384367 | 14.07.12 | 14.09.12 | 62.0 | 17 | 12 | 35% | 4 |
| 384376 | 14.07.12 | 14.09.12 | 62.0 | 28 | 19 | 31% | 6 |
| 384373 | 14.07.12 | 14.09.12 | 62.0 | 39 | 26 | 28% | 7 |
| 384372 | 14.07.12 | 14.09.12 | 62.0 | 15 | 10 | 36% | 4 |
| 384371 | 14.07.12 | 14.09.12 | 62.0 | 27 | 18 | 31% | 6 |
| 384370 | 14.07.12 | 14.09.12 | 62.0 | 40 | 27 | 28% | 8 |
| 384374 | 14.07.12 | 14.09.12 | 62.0 | 17 | 11 | 35% | 4 |
| 384375 | 14.07.12 | 14.09.12 | 62.0 | 135 | 91 | 21% | 19 |
| 384311 | 13.07.12 | 13.09.12 | 62.0 | 50 | 33 | 26% | 9 |
| 384312 | 13.07.12 | 13.09.12 | 62.0 | 25 | 17 | 32% | 5 |
| 384357 | 14.07.12 | 14.09.12 | 62.0 | 39 | 26 | 28% | 7 |
| 384354 | 14.07.12 | 14.09.12 | 62.0 | 20 | 13 | 34% | 4 |
Table 2. Continued.

| Code    | Start Date  | End Date   | Radon Concentration | Frequency | Radon Level |
|---------|-------------|------------|---------------------|-----------|-------------|
| 384356  | 14.07.12    | 14.09.12   | 62.0                | 34        | 29%         |
| 384313  | 13.07.12    | 13.09.12   | 62.0                | 41        | 28%         |
| 384310  | 13.07.12    | 13.09.12   | 62.0                | 12        | 39%         |
| 384353  | 14.07.12    | 14.09.12   | 62.0                | 28        | 31%         |
| 384351  | 14.07.12    | 14.09.12   | 62.0                | 41        | 28%         |

From these tables we find that the average indoor radon concentration value for houses in this area was found to vary from $11 \pm 6$ Bq m$^{-3}$ to $380 \pm 91$ Bq m$^{-3}$ in winter season and from $8 \pm 3$ Bq m$^{-3}$ to $356 \pm 64$ Bq m$^{-3}$ in summer season. The highest average indoor concentration was $380 \pm 91$ Bq m$^{-3}$ in winter season and $356 \pm 64$ Bq m$^{-3}$ in summer season. These values are upper the recommended threshold of 200-300 Bq/m$^3$ in summer and winter season. The lowest average indoor concentration was $11 \pm 6$ Bq m$^{-3}$ in winter season and $8 \pm 3$ Bq m$^{-3}$ in summer season. The radiation from radon and its daughter products, is considered the second leading cause of lung cancer after smoking, according to a 1999 report the National Academy of Science (NAS Reports, 1998).

The World Health Organization (WHO, 2009) has suggested that homeowners take actions when radon levels exceed 100 Bq/m$^3$. This is a much more conservative figure than the Environmental Protection Agency (EPA) action level of 148 Bq/m$^3$ (EPA, 1991), which has been the USA standard for many years (Mowlavi, 2012). The upper limit value of radon by TAEK is 400 Bq/m$^3$.

In this study, we calculated annual effective dose utilizing UNSCEAR’s guidelines (UNSCEAR, 2000). Their suggestions are as follows:

- An indoor radon decay product equilibrium factor of EF = 0.4
- A radon effective dose coefficient factor of EDCF = 9nSv/(Bq h m$^{-3}$)
- An indoor occupancy factor of OF = 0.8, which is the fraction time that people spend indoors, but not essentially in their homes. Therefore, during one year (T= 365x24 h), people spend about 7,008 hours in home and office environments.

Annual effective dose value is given in Eq.3.

$$D = (C_{Ra}) \times (EF) \times (EDCF) \times (OF) \times (T)$$

$$D = [11 \text{ Bq/m}^3] \times [0.4] \times [9 \times 10^{-9} \text{ (Sv)/(Bq h m}^{-3})] \times [0.8] \times [8760 \text{ (h)}]$$

$$D = 0.278 \text{ mSv}$$

The calculated values of average annual effective dose for study area in winter season vary from 0.278 mSv to 9.59 mSv. The calculated values of average annual effective dose for study area in summer season vary from 0.202 mSv to 8.98 mSv. These annual effective dose values are less than even the
lower limit of suggested action level (3-10 mSv). Therefore, the calculated average annual effective dose values do not exceed the Turkish average. No difference was found when the results of the study were compared with the data acquired from other provinces of Turkey (Canbazoğlu, 2012). Further, the average annual effective dose values is more than the accepted value of 1.3 mSv, as set by UNSCEAR in 1993, but on the lower side of recommendation level of (3-10 mSv). For this reason, these average values will pose none serious health risk.

These winter season radon measurements are expected to be higher than other times of the year, especially in poorly ventilated houses. The distribution of indoor radon levels among number of dwellings in Erzurum is shown in Fig. 3 in winter season and in Fig. 4 in summer season.

![Distribution of radon concentration among various dwellings in winter season](image.png)

**Fig. 3.** Distribution of radon concentration among various dwellings in winter season
In winter season, radon concentrations in 43.6% of houses range between 0 and 20 Bq/m$^3$. 25.5% of them range between 21 and 40 Bq/m$^3$. 12.8% of them range between 41 and 60 Bq/m$^3$. 4.3% of them range between 61 and 80 Bq/m$^3$. 4.3% of them range between 81 and 100 Bq/m$^3$. 1.06% of them range between 101 and 120 Bq/m$^3$. 2.13% of them range between 121 and 140 Bq/m$^3$. 2.13% of them range between 141 and 160 Bq/m$^3$. 1.06% of them range between 161 and 180 Bq/m$^3$. 1.06% of them range between 181 and 200 Bq/m$^3$. 2.85% of them range between 201 and 220 Bq/m$^3$. 0.95% of them range between 221 and 240 Bq/m$^3$. 0.95% of them range between 241 and 260 Bq/m$^3$. 0.95% of them range between 261 and 280 Bq/m$^3$. 0.95% of them range between 281 and 300 Bq/m$^3$. 2.85% of them range between 301 and 320 Bq/m$^3$. 1.9% of them range between 321 and 340 Bq/m$^3$. 0.95% of them range between 341 and 360 Bq/m$^3$. 0.95% of them range between 361 and 380 Bq/m$^3$. 2.85% of them range between 381 and 400 Bq/m$^3$.

In summer season, radon concentrations 23.8% of houses range between 0 and 20 Bq/m$^3$. 40% of them range between 21 and 40 Bq/m$^3$. 12.4% of them range between 41 and 60 Bq/m$^3$. 5.7% of them range between 61 and 80 Bq/m$^3$. 2.85% of them range between 81 and 100 Bq/m$^3$. 2.85% of them range between 101 and 120 Bq/m$^3$. 0.95% of them range between 121 and 140 Bq/m$^3$. 0.95% of them range between 141 and 160 Bq/m$^3$. 2.85% of them range between 161 and 180 Bq/m$^3$. 1.9% of them range between 181 and 200 Bq/m$^3$. 0.95% of them range between 201 and 220 Bq/m$^3$. 0.95% of them range between 221 and 240 Bq/m$^3$. 0.95% of them range between 241 and 260 Bq/m$^3$. 0.95% of them range between 261 and 280 Bq/m$^3$. 0.95% of them range between 281 and 300 Bq/m$^3$. 2.85% of them range between 301 and 320 Bq/m$^3$. 1.9% of them range between 321 and 340 Bq/m$^3$. 0.95% of them range between 341 and 360 Bq/m$^3$. 0.95% of them range between 361 and 380 Bq/m$^3$. 2.85% of them range between 381 and 400 Bq/m$^3$.

![Radon Concentration Distribution](image)

**Fig 4.** Distribution of radon concentration among various dwellings in summer season.
1.9 % of them range between 221 and 240 Bq/m$^3$.
0.95 % of them range between 261 and 280 Bq/m$^3$.
0.95 % of them range between 301 and 320 Bq/m$^3$.
0.95 % of them range between 361 and 380 Bq/m$^3$.

It is found that the radon levels depend upon many factors inside in dwellings. The radon levels in dwellings vary with seasons. Ventilation plays an important role. During the winter months door and windows tend to be closed, concentrating the radon counts. Radon levels are usually higher in winter compared to summer. Also, radon concentrations vary with the floor levels. Therefore, people in basement would have a greater risk for exposure.

In conclusion, the result of present study provides a database on indoor radon level in Erzurum, Turkey.

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