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Measurements of Indoor ^{222}Rn in Igdir, Turkey with CR-39 Detectors

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The increasing awareness concerning the harmful effects of radiation on organic structures develop an interest to researchers to investigate the sources and impacts within the environment. In nature, the most common source of radiation comes from (a) cosmic rays, (b) γ-rays and (c) radon gas. The main radioactive elements in earth's crust are ^{40}K, ^{238}U, ^{232}Th series, *etc*. It has been observed that nearly 50 % of the radiation exposed to in daily life comes from Rn isotopes, especially from ^{222}Rn. The radon gas produced by the decay of ^{238}U in rocks diffuses into the environment *via* soil, water and eventually, the atmosphere. Low lying places such as cellars, basements and unventilated enclosures can accumulate Rn concentrations to unhealthy levels. Therefore, exposure of radon and radon-decay daughter elements is a potential public health problem. Radon monitoring by the Turkish Atomic Energy Agency began in 1984 and most major cities have accumulated base line information, except the Igdir region. Therefore, the main goal of this study is to determine ^{222}Rn activity concentration in houses and public buildings in Igdir region. CR-39 nuclear trace detectors were used in these measurements. Tracks were read and treated by radosys electronic equipment. According to the results, it is found that radon activity concentration is 23-202 Bq/m^3 in winter. Mean value for houses was found as 87 Bq/m^3.

Keywords: Radon, Radiation, CR-39 nuclear trace detector.

INTRODUCTION

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 colourless, odorless and tasteless gas detectable by special equipment. Basically, radon is drawn into the house by virtue of the reduced pressure of the utilizing air inside due to domestic heating. Along with air, the majority of radon is drawn into the house through the floor *via* small cracks and gaps between heating and water pipes [1]. It also permeates small cracks in the walls and it is present in the water supply. Variations in house heating and ventilation and in weather conditions affecting the ground itself result in wide seasonal fluctuations of radon levels in any house [2].

Over the last several decades, there has been an increasing interest in the measurement of indoor radon concentration levels throughout the world. The link between radon and cancer is compelling, especially the correlation between non-smokers and lung cancer [3-5]. Therefore, measurements of indoor radon play a critical role in monitoring human health and safety. 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. 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 [6,7]. Indoor radon measurements and its application by nuclear track detectors in secondary schools in Serbia were performed in the spring in 2004. Thirty detectors (type CR-39) were distributed to high school teachers in several cities of Serbia [8]. In another work, a high-purity germanium detector has been used to measure the abundance of radium, thorium and potassium in building materials used in Sicilian dwellings. The results are discussed and the criterion is indicated to reduce the radiation dose to humans [9].

To investigate the statistical relationship between indoor radon, house type and building ground specifications, measurements of the indoor radon concentration have been carried out in more than 10,000 dwellings in different regions of Germany [10]. In Pakistan, researchers determined the exact seasonal variation of the indoor radon levels by meteorological factor [11].

In addition, the indoor radon (^{222}Rn) activity concentration was measured between January and June in the schools of two geothermal areas in Tuscany, central Italy. Only a slight difference in the concentrations between two major sampling areas was found. This was related to different geological characteristics of ground and not the presence of the geothermal plants [12].

Throughout 2009, seasonal indoor radon concentration measurements in dwellings in all regions of the Former Yugoslav Republic of Macedonia were collected using CR-39 track detectors over four successive three month periods (winter, spring, summer and autumn). The results of analysis variance showed statistically significant differences between indoor radon concentrations in different seasons [13]. Furthermore, in Eastern Sicily, the results of a long-term survey of radon concentrations were conducted from 2005 to 2010 in schools and dwellings, revealing concentrations of radon [14]. Many governments have set safety standards recommending radon exposures in dwellings and indoor workplaces. In general, residential radon is considered unhealthy in concentrations between 200 and 300 Bq/m^3 based on ICPR recommendation [15]. Further, to demonstrate that no level of radon is safe, an increase in lung cancer risk has been observed with exposure levels below 200 Bq/m^3 [16].

Turkey has conducted radon surveys in many cities [17-21]. However, indoor radon measurements for Igdir province is not available in the literature. Therefore, the aim of our study is to assess any health risk from radon in this area. Igdir, located in the northeastern part of Turkey. The city is found on 39º 53' 37'' N, 43º 59' 52'' E coordinates. Present study included measurements of 81 dwellings, using CR-39 track detectors between the months of January to March 2011.

EXPERIMENTAL

Measurements are normally carried out using passive detectors. Measurements over several months are better than short-term measurements for estimating annual average radon levels. Radon levels are known to vary from day to day, season to season and with the region's geology [22,23].

The plastic track etch detectors are the most common methods to measure radon levels [24,25]. For this reason, the indoor radon activity concentrations were measured by CR-39 nuclear track detectors. A total of 81 of these units were placed in houses at the center of Igdir city and extended 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 their time, such as living rooms and bedrooms. Average exposure time of CR-39 detectors was 60 days. Detectors were placed in the selected houses, at least 1 m from the floor and away from doors or windows.

Detectors were provided from Çekmece Nuclear Research and Training Center. CR-39 detector is a small piece of special plastic or film inside a small container. CR-39 detector is a cylindrical chamber with a radius of 26 mm and a height of 55 mm. Air is tested by entering through a filter covering a hole in the container. It is then sealed and sent to the lab for testing. CR-39 is made by the polymerization of diethyleneglycolbis-allylcarbonate (ADC). The monomer structure is $C_{12}H_{18}O_7$ [26].

Oxygen has the largest atomic radius and more electrons in its orbits. The α-particles emitted from the decay of radon interact with the oxygen atoms. When an α-particle passes through the film, it collides with the electrons of the oxygen atoms and loses almost all of their energy. This process leads to the positive ionization of oxygen atoms in detector film.

The track can be made visible by etching the material in strong acidic [27] or basic solutions [28]. But base solution are mostly used. The detectors were etched in a 25 % solution of NaOH at a constant temperature of 90 °C in 4 h. The negative ionizations in the solution interact with the positive ionizations of the oxygen atoms in the detector film. They break the ester bonds of the oxygen atoms, altering its structure. This leads to the formation of small "pits" on the film's surface upon etching. These pits can be counted using a conventional optical microscope.

The tracks were read and treated by RADOSYS electronic equipment. This sophisticated equipment includes RADOBATH (thermostatic bath for chemical etching of traces on the detectors) and RADOMETER equipment for reading tracks, with a B&W CCD camera and a compatible PC. The optimal use of any track detector is largely dependent on the standardization of various etching parameters, such as the bulk etch rate (V_b) and track etch rate (V_t), both of which must be experimentally determined under suitable conditions. Systematic experiments were performed to determine the optimal etching condition. The tracks within a predetermined area were counted and the number of tracks per area determined the radon concentration of the site. Figs. 1a and 1b show tracks of high and low density CR-39 detectors, respectively.

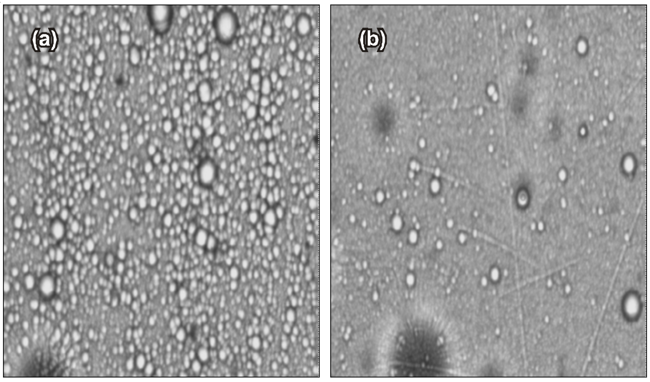

Fig. 1. Tracks of high and low density CR 39 detectors

Statistical: SPSS 20 program was used for the statistical analysis of present data. SPSS is a comprehensive and flexible statistical analysis and data management solution. SPSS can take data from almost any type of file and use them to generate tabulated reports, charts and plots of distributions and trends, descriptive statistics and conduct complex statistical analyses [29].

In order to determine whether the independent variable had a significant impact on the dependent variable, the F-test was applied to the data. The f-test was used to examine the relationship between the dependent variable and the set of independent variable. The value of f was obtained through the ANOVA calculation in SPSS. One-way Analysis of Variance (ANOVA) can be used for the case of a quantitative outcome with a categorical explanatory variable that has two or more levels of treatment.

Various methods have been developed for doing multiple comparisons of group means. In SPSS, one way to accomplish this is *via* use of POSTHOC parameter on the one-way command. LSD stands for least significant difference t-test. This test does not control the overall probability of rejecting the hypotheses that some pairs of means are different, while in fact they are equal, *i.e.* it doesn't matter if you are comparing 1 pair of means or a 100, no adjustment is made for the number of comparisons. Tukey's multiple comparison test is one of several tests that can be used to determine which means amongst a set of means differ from the rest.

RESULTS AND DISCUSSION

The measurements for indoor radon concentration levels were made in 81 houses from January to March. During the winter months, door and windows tend to be closed, concentrating on the radon counts. The results of these measurements are shown in Tables 1a and 1b.

TABLE-1a
VALUES OF INDOOR RADON CONCENTRATION

Detector No.	Measurement time (h)	Floor level	Radon concentration (Bq/m^3)
R86504	1440	Basement	190 ± 9.5
R86540	1488	First floor	70 ± 3.5
R86548	1488	Basement	120 ± 6.0
R86584	1488	First floor	83 ± 4.1
R86604	1488	Second floor	67 ± 3.3
R86610	1512	First floor	77 ± 3.8
R86619	1488	First floor	30 ± 1.5
R86620	1488	Basement	74 ± 3.7
R86636	1488	Basement	68 ± 3.4
R86640	1488	Second floor	69 ± 3.4
R86645	1488	Second floor	58 ± 2.9
R86646	1488	Basement	91 ± 4.5
R86647	1464	Basement	108 ± 5.4
R86653	1488	First floor	76 ± 3.8
R86668	1488	First floor	90 ± 4.5
R86674	1488	Basement	75 ± 3.7
R86679	1488	Basement	74 ± 3.7
R89235	1488	Basement	174 ± 8.7
R89237	1488	First floor	74 ± 3.7
R89240	1464	First floor	84 ± 4.2
R89249	1512	First floor	113 ± 5.6
R89250	1512	First floor	68 ± 3.4
R89254	1488	Second floor	55 ± 2.7
R89256	1488	First floor	82 ± 4.1
R89269	1488	Basement	95 ± 4.7
R89271	1440	Basement	124 ± 6.2
R89287	1488	Basement	81 ± 4.0
R89289	1512	First floor	82 ± 4.1
R89299	1512	Second floor	68 ± 3.4
R89308	1512	Basement	77 ± 3.8
R89386	1488	First floor	108 ± 5.4
R89387	1440	First floor	84 ± 4.2
R89397	1488	Second floor	77 ± 3.8
R89406	1488	Basement	114 ± 5.7
R90149	1488	First floor	79 ± 3.9
R90150	1512	Second floor	66 ± 3.3
R90153	1512	Basement	97 ± 4.8
R90154	1464	Basement	147 ± 7.3
R90157	1440	First floor	50 ± 2.5
R90160	1512	Basement	81 ± 4.0
R90168	1488	Basement	65 ± 3.2
R90170	1512	Second floor	60 ± 3.0
R90172	1512	Basement	110 ± 5.5
R90175	1488	Basement	72 ± 3.6

TABLE-1b
INDOOR RADON CONCENTRATION VALUES

Detector No.	Measurement time (h)	Floor level	Radon concentration (Bq/m^3)
R90176	1488	Basement	116 ± 5.8
R90177	1488	Basement	122 ± 6.1
R90186	1488	First floor	75 ± 3.7
R90187	1488	Basement	109 ± 5.4
R90190	1440	First floor	49 ± 2.4
R90192	1488	Basement	81 ± 4.0
R90199	1488	Second floor	72 ± 3.6
R90200	1440	Basement	122 ± 6.1
R90201	1512	First floor	64 ± 3.2
R90205	1488	Basement	98 ± 4.9
R90209	1488	Basement	94 ± 4.7
R90215	1512	Basement	106 ± 5.3
R90220	1488	First floor	116 ± 5.8
R90221	1488	Basement	84 ± 4.2
R90222	1464	Basement	116 ± 5.8
R90227	1488	Basement	132 ± 7.6
R90230	1512	Basement	117 ± 5.8
R90234	1512	Basement	98 ± 4.9
T21928	1512	Second floor	38 ± 1.9
T21936	1512	First floor	23 ± 1.1
T21940	1512	First floor	81 ± 4.0
T21945	1512	Second floor	77 ± 3.8
T21964	1488	Basement	88 ± 4.4
T21972	1512	Basement	56 ± 2.8
T21996	1488	Basement	90 ± 4.5
T22016	1512	Second floor	58 ± 2.9
T22025	1488	First floor	46 ± 2.3
T22029	1512	Basement	75 ± 3.7
T22048	1464	First floor	61 ± 3.0
T22053	1464	Basement	75 ± 3.7
T22072	1440	Basement	126 ± 6.3
T22084	1464	Basement	74 ± 3.7
T22092	1440	Basement	202 ± 1.0
T22132	1512	Basement	135 ± 6.7
T22143	1512	First floor	85 ± 4.2
T22144	1512	Second floor	55 ± 2.7
T22181	1512	First floor	34 ± 1.7

The radiation from radon and its daughter products is considered the second leading cause of lung cancer after smoking, according to a 1999 report by the National Academy of Science [30]. World Health Organization [31] has suggested that homeowners should 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 [32] which has been the USA standard for many years [33]. The upper limit value of radon by TAEK is 400 Bq/m^3.

The average indoor radon concentration value for houses in this area was 87 Bq/m^3.The highest average indoor concentration was 23 Bq/m^3 and the lowest average indoor concentration was 202 Bq/m^3. These values are below the recommended threshold of 200-300 Bq/m^3.

In this study, we calculated annual effective dose utilizing UNSCEAR's guidelines [34]. Their suggestions are as follows:

- An indoor radon decay product equilibrium factor of EF = 0.4.
- A radon effective dose coefficient factor of EDCF = 9 nSv/(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, in one year (T = 365 × 24 h), people spend about 7,008 h in home and office environments.

Annual effective dose value is given in eqn. 3:

$$D = (C_{Rn}) \times (EF) \times (EDCF) \times (OF) \times (T) \quad (3)$$

$$D = [87\ Bq/m^3] \times [0.4] \times [9x10^{-9}\ (Sv)/(Bq\ h\ m^{-3})] \times [0.8] \times [8760\ (h)]$$

$$D = 2.19\ mSv$$

The calculated values of average annual effective dose for the study area varied from 0.58 to 50.96 mSv with a mean value of 2.19 mSv.The average annual effective dose value, 2.19 mSv, is less than even the lower limit of suggested action level (3-10 mSv). Therefore, the calculated value for average annual effective dose of 2.19 mSv does not exceed Turkish average. No difference was found when the results of the study were compared with the data acquired from other provinces of Turkey [18]. Further, the average annual effective dose of 2.19 mSv is more than the accepted value of 1.3 mSv set by UNSCEAR in 1993 [35], but on the lower side of the recommendation level of 3-10 mSv. For this reason, this average value will pose no serious health risk [36].

These winter radon measurements are expected to be higher than those in other seasons of the year, especially in poorly ventilated houses. SPSS 20 program was used for the statistical analysis of these data. The histogram and normal distributions of radon of indoor radon levels among 81 houses in Igdir is shown in Fig. 2. Radon concentrations in 4.9 % of houses ranged between 0 and 40 Bq/m^3. 1.1 % of them ranged between 41 and 60 Bq/m^3. 32 % of them ranged between 61 and 80 Bq/m^3. 24.7 % of them ranged between 81 and 100 Bq/m^3. 14.8 % of them ranged between 101 and 120 Bq/m^3. 4.9 % of them ranged between 121 and 140 Bq/m^3. 3.7 % of them ranged between 141 and 160 Bq/m^3. 3.69 % of houses were higher than 160 Bq/m^3.

Relationship between the radon concentration and floor levels was also investigated. Means of radon active concentration are found 103.64, 72.46 and 63.08 for basement, first floor and second floor, respectively (Fig. 3 and Table-2a). The result of this statistical analysis is shown in Tables 2a-2d. Radon action concentration was chosen as dependent variable, whilst our independent variable was floor level. These results suggest a significant relationship between radon concentration and floor level.

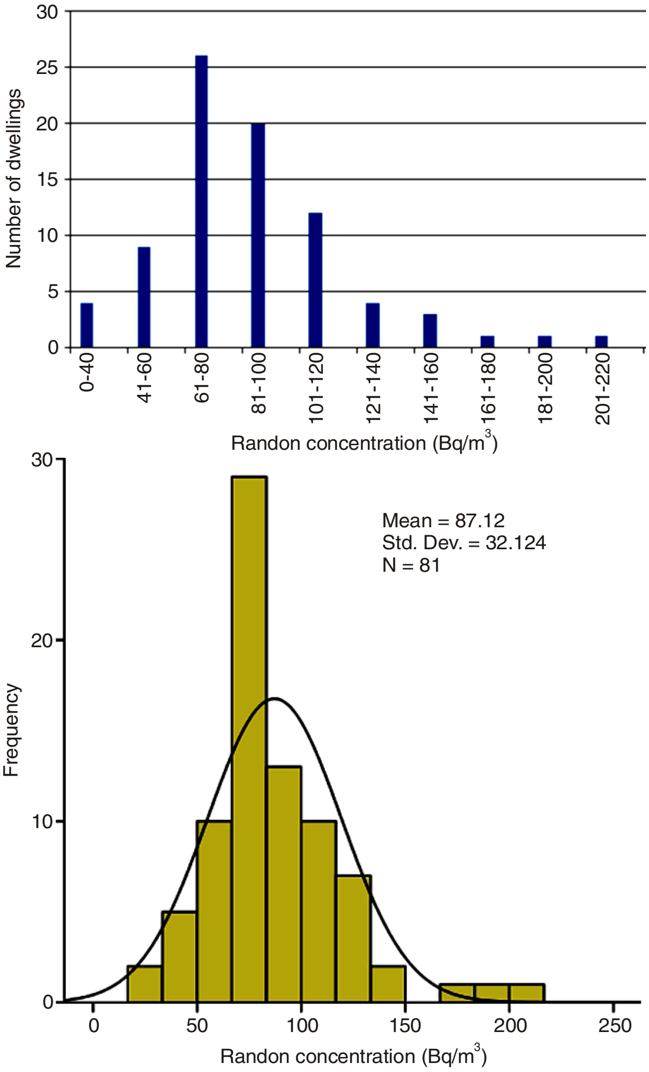

Fig. 2. Histogram and normal distributions of radon of various dwellings in Igdir province

TABLE-2b
MODEL SUMMARY

Model	R	R square	Adjusted R^2	Std. error of the estimate
1	0.511	0.261	0.252	27.787

a. Predictors: (Constant) floor level
b. Dependent variable: Radon action concentration

The variance value (R^2) (Table-2b), was found to be 0.261. An ANOVA calculation suggests that the model is robust in explaining the data. The ratio of the sums of squares of the model to the total sums of squares is $R^2 = 21560.682/82556,765 = 0.261$. The SPSS output for ANOVA is fairly concise. The most significant value to interpret is a *p*-value. The last column of the ANOVA table is the significant value (Table-2c). Because the *p*-value is 0.001, which is less than the significance level ($p \leq 0.05$), the differences of between radon

TABLE-2a
DESCRIPTIVE STATISTICS OF INDOOR RADON CONCENTRATION
MEASUREMENTS RELATIVE FLOOR LEVELS IN IGDIR PROVINCE

	N	Mean	Std. deviation	Std. error	95 % Confidence interval for mean		Min.	Max.
					Lower bound	Upper bound		
Basement	42	103.642	32.355	4.992	93.560	113.725	56.00	202.00
First floor	26	72.461	23.406	4.590	63.007	81.915	23.00	116.00
Second floor	13	63.076	10.688	2.964	56.617	69.535	38.00	77.00
Total	81	87.123	32.124	3.569	80.020	94.226	23.00	202.00

TABLE-2c
COMPARISON OF THE RELATIONSHIP BETWEEN RADON CONCENTRATION AND FLOOR WITH ONE WAY ANOVA TEST

	Sum of Squares	df	Mean square	F	Sig.
Between groups	24567.738	2	12283.869	16.523	0.000
Within groups	57989.027	78	743.449		
Total	82556.765	80			

TABLE-2d
COMPARISON OF THE RELATIONSHIP BETWEEN RADON CONCENTRATION AND FLOOR WITH TUKEY AND LSD TESTS

	(I) Floor level	(J) Floor level	Mean difference (I-J)	Std. error	Sig.	95 % Confidence interval	
						Lower bound	Upper bound
Tukey HSD	Basement	First floor	31.18132*	6.80407	0.000	14.9246	47.4380
		Second floor	40.56593*	8.65388	0.000	19.8896	61.2423
	First floor	Basement	-31.18132*	6.80407	0.000	-47.4380	-14.9246
		Second floor	9.38462	9.26189	0.571	-12.7445	31.5137
	Second floor	Basement	-40.56593*	8.65388	0.000	-61.2423	-19.8896
		First floor	-9.38462	9.26189	0.571	-31.5137	12.7445
LSD	Basement	First floor	31.18132*	6.80407	0.000	17.6355	44.7272
		Second floor	40.56593*	8.65388	0.000	23.3374	57.7945
	First floor	Basement	-31.18132*	6.80407	0.000	-44.7272	-17.6355
		Second floor	9.38462	9.26189	0.314	-9.0544	27.8236
	Second floor	Basement	-40.56593*	8.65388	0.000	-57.7945	-23.3374
		First floor	-9.38462	9.26189	0.314	-27.8236	9.0544

Dependent variable: Radon concentration; *Mean difference is significant at 0.05 level.

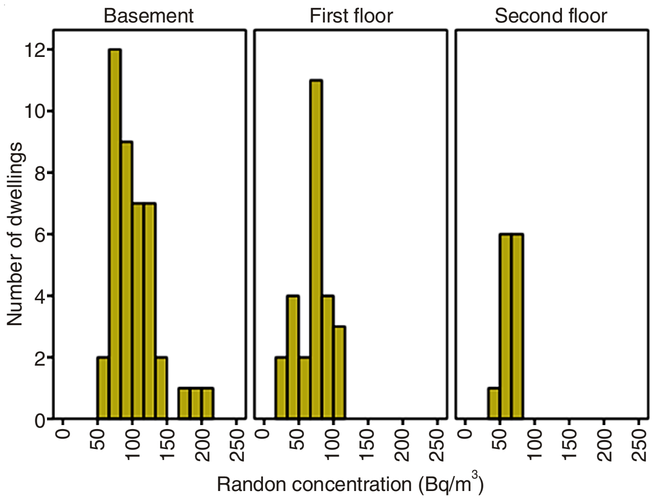

Fig. 3. Relationship between the radon concentration and floor number

concentration of the means for several floor levels are statistically significant. The data show that there is a highly significant effect of floor level on the radon action concentration, accounting for nearly 26 % of the variance.

Tukey and least significant difference t test (LSD) test was applied to understand the variance between floor levels. There were lots of different tests that we could have chosen, but they would have given us different answers (Table-2d). From the resulting table, the means of the basement are compared with the means of the two other floors. It should be noted that the difference between the basement and the first floor is the same as the difference between the first floor and the basement; the sign is only reversed. There was a significant relationship between the basement and the first floor. Again, there was a significant relationship between the mean difference of the basement and the mean difference of the second floor. However, there was no significant relationship between the first and second floor. As a result, it can be seen that all differences among the means are significant $p \leq 0.05$ except the difference between the first floor and second floor (p = 0.571, 0.314). Generally, radon levels are usually very high in the basements and enclosed rooms. Radon concentrations decreased on first floor and more so in the second floor. Therefore, people in basements would have a greater risk of exposure. Table-2e showed a comparison of the present results with data reported for other city of Turkey. Comparison with the these data suggests that the mean measured indoor radon concentration value for Igdir locate middle values in the those reported values. In conclusion, the results of the present study provide a database on indoor radon level in Igdir, Turkey. The reported values of indoor radon concentration in present study are lower than the radon action level 200-600 Bq/m^3 as proposed by ICRP-1993, the new reference level (100 Bq/m^3) set by WHO.

TABLE-2e
COMPARISON OF PRESENT RESULTS WITH OTHER RESULTS IN VARIOUS LOCATIONS IN TURKEY

Country	Mean radon concentration (Bq/m^3)	Ref.
Sivas	89	[18]
Batman	84	[21]
Istanbul	50	[37]
Izmir	70	[38]
Karabük	131	[39]
Giresun	130	[40]
Tekirdag	87	[41]
Manisa	97	[42]
Kilis	50	[43]
Osmaniye	51	[43]
Igdir	87	Present study

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