

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 ± 6 Bq m⁻³ - 380 ± 91 Bq m⁻³ in winter season and 8 ± 3 Bq m⁻³ - 356 ± 64 Bq m⁻³ in summer season. We found that the ²²²Rn effective dose values in the studied dwellings in winter season range from 0.278 to 9.59 mSv y⁻¹. Also, the ²²²Rn 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 (²²²Rn) 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 (²²²Rn) 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) α 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).

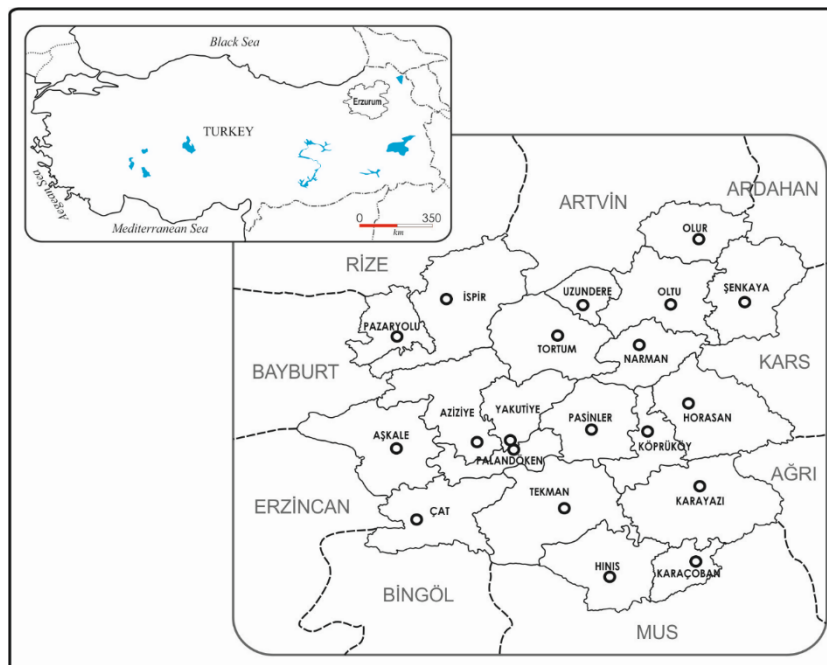


Fig 1. Map showing the studied area of Erzurum Province in Turkey.

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 $39^{\circ} 54' 35''$ N, $41^{\circ} 16' 32''$ 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.



Fig. 2. Nuclear track detector LR-115.

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 ($C_6H_2O_9N_2$) 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 °C 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.

Table1. 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/m ³	Avg. radon conc. Bq/m ³	Uncertainty 2 σ	
						$\pm$ %	$\pm$ Bq/m ³
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

Table1. Continued.

384206	14.02.12	14.04.12	60.0	30	21	46%	10
384171	13.02.12	13.04.12	60.0	71	50	36%	18
384172	13.02.12	13.04.12	60.0	22	16	49%	8
384174	13.02.12	13.04.12	60.0	85	59	34%	20
384176	13.02.12	13.04.12	60.0	42	29	42%	12
384177	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
384173	13.02.12	13.04.12	60.0	279	194	27%	52
384175	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
384159	12.02.12	12.04.12	60.0	172	119	29%	35
384180	12.02.12	12.04.12	60.0	29	20	46%	9
384191	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
384183	12.02.12	12.04.12	60.0	34	24	44%	11
384184	12.02.12	12.04.12	60.0	32	22	45%	10
384185	12.02.12	12.04.12	60.0	25	17	48%	8
384186	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
384187	13.02.12	13.04.12	60.0	36	25	43%	11
384198	13.02.12	13.04.12	60.0	110	77	32%	25
384188	13.02.12	13.04.12	60.0	45	31	41%	13
384189	13.02.12	13.04.12	60.0	69	48	36%	17
384190	13.02.12	13.04.12	60.0	41	28	42%	12
384192	13.02.12	13.04.12	60.0	28	19	46%	9
384193	13.02.12	13.04.12	60.0	28	19	46%	9
384243	16.02.12	16.04.12	60.0	32	22	45%	10
384242	16.02.12	16.04.12	60.0	43	30	41%	12
384194	13.02.12	13.04.12	60.0	49	34	40%	14

Table1. Continued.

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/m ³	Avg. radon conc. Bq/m ³	Uncertainty 2 σ	
						$\pm$ %	$\pm$ Bq/m ³
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
384282	12.07.12	12.09.12	62,0	36	24	29%	7
384283	12.07.12	12.09.12	62,0	143	96	21%	20
384286	12.07.12	12.09.12	62,0	19	13	34%	4
384284	12.07.12	12.09.12	62,0	25	17	32%	5
384285	12.07.12	12.09.12	62,0	25	17	32%	5
384278	12.07.12	12.09.12	62,0	22	15	33%	5
384277	12.07.12	12.09.12	62,0	48	32	27%	9
384276	12.07.12	12.09.12	62,0	28	19	31%	6
384279	12.07.12	12.09.12	62,0	196	132	20%	26
384275	12.07.12	12.09.12	62,0	18	12	34%	4
384273	12.07.12	12.09.12	62,0	17	11	35%	4
384274	12.07.12	12.09.12	62,0	42	29	28%	8
384281	12.07.12	12.09.12	62,0	53	36	26%	9
384280	12.07.12	12.09.12	62,0	36	24	29%	7
384272	12.07.12	12.09.12	62,0	65	43	25%	11
384303	12.07.12	12.09.12	62,0	62	41	25%	10
384304	12.07.12	12.09.12	62,0	36	24	29%	7
384306	12.07.12	12.09.12	62,0	28	19	31%	6
384307	12.07.12	12.09.12	62,0	91	61	23%	14
384305	12.07.12	12.09.12	62,0	71	48	24%	12
384309	12.07.12	12.09.12	62,0	24	16	32%	5
384296	12.07.12	12.09.12	62,0	73	49	24%	12
384297	12.07.12	12.09.12	62,0	150	100	21%	21
384299	12.07.12	12.09.12	62,0	23	16	32%	5
384298	12.07.12	12.09.12	62,0	64	43	25%	11
384301	12.07.12	12.09.12	62,0	13	9	38%	3
384293	12.07.12	12.09.12	62,0	44	30	27%	8
384294	12.07.12	12.09.12	62,0	33	22	30%	7
384302	12.07.12	12.09.12	62,0	14	10	37%	4

Table2. Continued.

384287	12.07.12	12.09.12	62,0	13	9	38%	3
384288	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

Table2. Continued.

384356	14.07.12	14.09.12	62,0	34	23	29%	7
384313	13.07.12	13.09.12	62,0	41	28	28%	8
384310	13.07.12	13.09.12	62,0	12	8	39%	3
384353	14.07.12	14.09.12	62,0	28	19	31%	6
384351	14.07.12	14.09.12	62,0	41	27	28%	8
384352	14.07.12	14.09.12	62,0	76	51	24%	12
384350	14.07.12	14.09.12	62,0	31	21	30%	6
384361	14.07.12	14.09.12	62,0	20	14	34%	5
384362	14.07.12	14.09.12	62,0	25	17	32%	5
384360	14.07.12	14.09.12	62,0	13	9	38%	3
384366	14.07.12	14.09.12	62,0	54	36	26%	9
384365	14.07.12	14.09.12	62,0	32	22	30%	7
384364	14.07.12	14.09.12	62,0	14	10	37%	4
384363	14.07.12	14.09.12	62,0	28	19	31%	6

From these tables we find that the average indoor radon concentration value for houses in this area was found to vary from $11 \pm 6 \text{ Bq m}^{-3}$ to $380 \pm 91 \text{ Bq m}^{-3}$ in winter season and from $8 \pm 3 \text{ Bq m}^{-3}$ to $356 \pm 64 \text{ Bq m}^{-3}$ in summer season. The highest average indoor concentration was $380 \pm 91 \text{ Bq m}^{-3}$ in winter season and $356 \pm 64 \text{ Bq m}^{-3}$ 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 $11 \pm 6 \text{ Bq m}^{-3}$ in winter season and $8 \pm 3 \text{ Bq m}^{-3}$ 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 $EDCF = 9\text{nSv}/(\text{Bq h m}^{-3})$
- 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 ($T = 365 \times 24 \text{ h}$), people spend about 7,008 hours in home and office environments.

Annual effective dose value is given in Eq.3.

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

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

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

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.

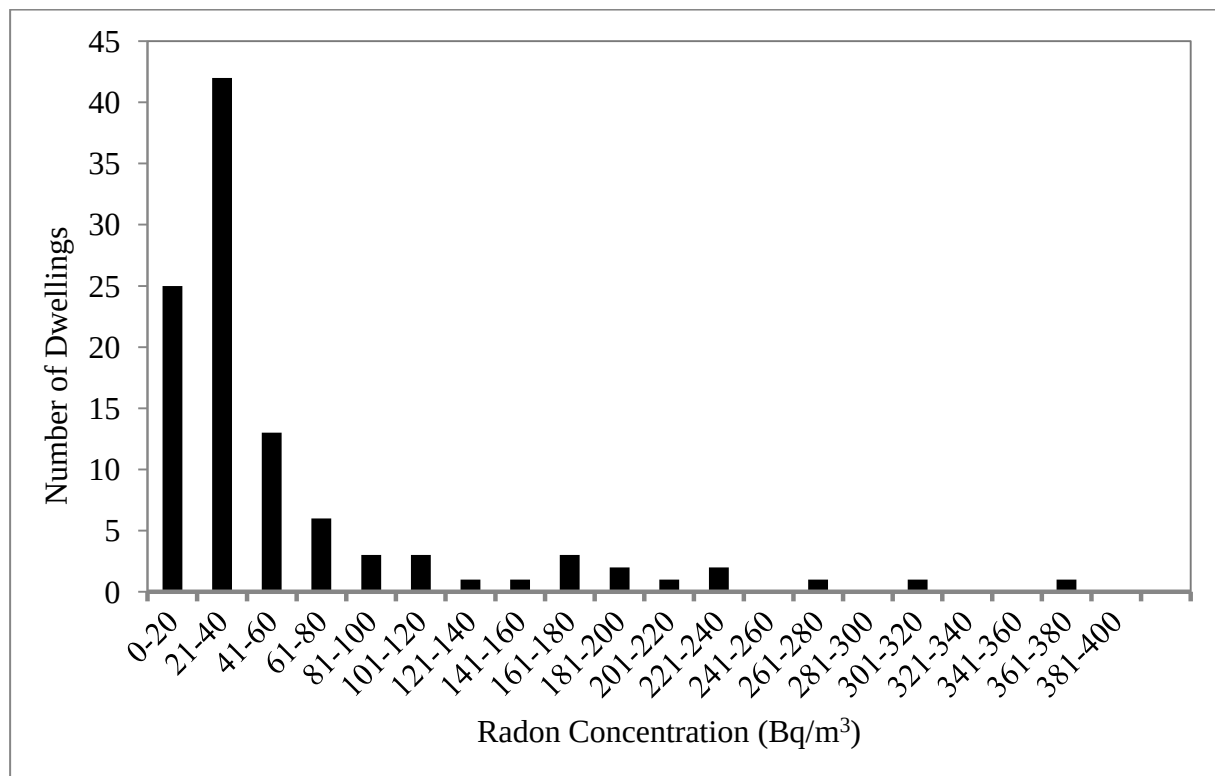


Fig. 3. Distribution of radon concentration among various dwellings in winter season

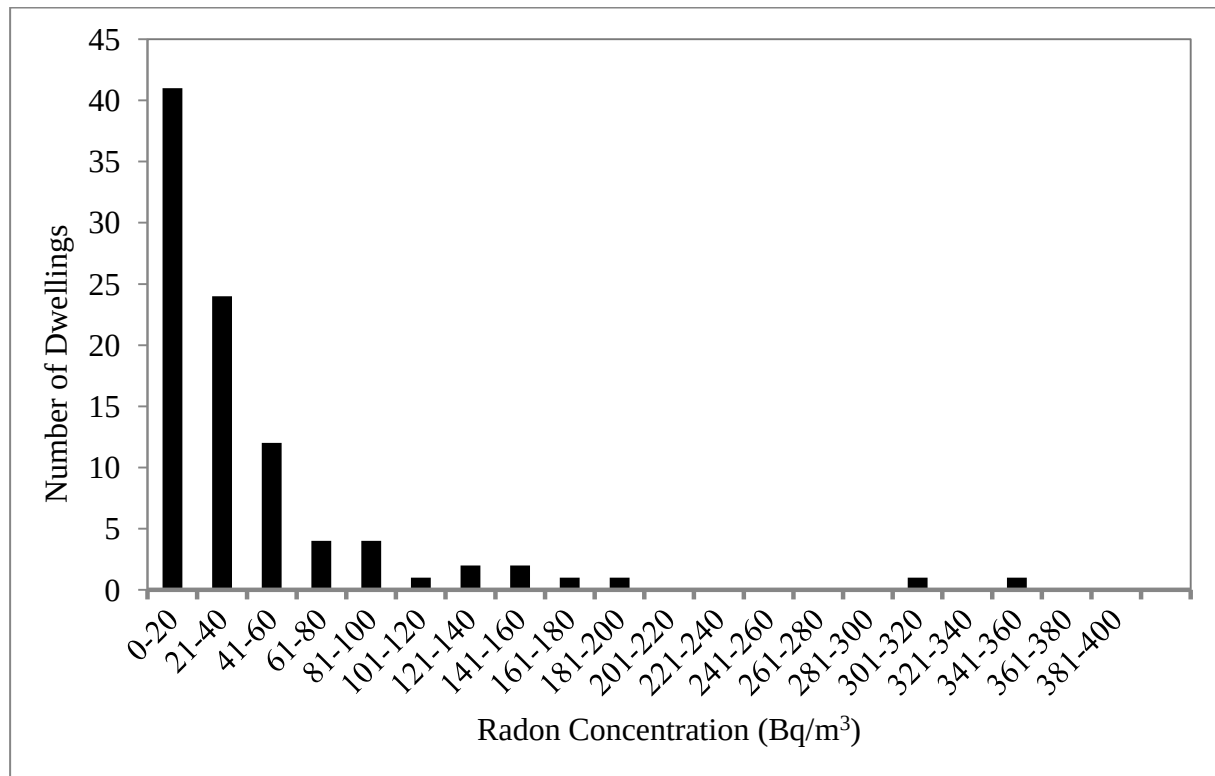


Fig 4. Distribution of radon concentration among various dwellings in summer season.

In winter season, radon concentrations in 43.6 % of houses range between 0 and 20 Bq/m³.

25.5 % of them range between 21 and 40 Bq/m³.

12.8 % of them range between 41 and 60 Bq/m³.

4.3 % of them range between 61 and 80 Bq/m³.

4.3 % of them range between 81 and 100 Bq/m³.

1.06 % of them range between 101 and 120 Bq/m³.

2.13 % of them range between 121 and 140 Bq/m³.

2.13 % of them range between 141 and 160 Bq/m³.

1.06 % of them range between 161 and 180 Bq/m³.

1.06 % of them range between 181 and 200 Bq/m³.

1.06 % of them range between 301 and 320 Bq/m³.

1.06 % of them range between 341 and 360 Bq/m³.

In summer season, radon concentrations 23.8 % of houses range between 0 and 20 Bq/m³.

40 % of them range between 21 and 40 Bq/m³.

12.4 % of them range between 41 and 60 Bq/m³.

5.7 % of them range between 61 and 80 Bq/m³.

2.85 % of them range between 81 and 100 Bq/m³.

2.85 % of them range between 101 and 120 Bq/m³.

0.95 % of them range between 121 and 140 Bq/m³.

0.95 % of them range between 141 and 160 Bq/m³.

2.85 % of them range between 161 and 180 Bq/m³.

1.9 % of them range between 181 and 200 Bq/m³.

0.95 % of them range between 201 and 220 Bq/m³.

- 1.9 % of them range between 221 and 240 Bq/m³.
- 0.95 % of them range between 261 and 280 Bq/m³.
- 0.95 % of them range between 301 and 320 Bq/m³.
- 0.95 % of them range between 361 and 380 Bq/m³.

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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