

# Seasonal and Regional Effects on Indoor Radon Levels and Effective Dose Rates in Afyonkarahisar Province

Hüseyin Ali Yalım<sup>1</sup>, Ayla Gümüş<sup>1</sup>, Ahmet Yıldız<sup>2</sup>, Duygu Açıl<sup>3</sup>, Merve Özçelik<sup>3</sup>, Rıdvan Ünal<sup>4</sup>

Afyon Kocatepe University, Science and Literature Faculty, Department of Physics, Afyonkarahisar, Turkey<sup>1</sup>

Afyon Kocatepe University, Engineering Faculty, Department of Geology Engineering, Afyonkarahisar, Turkey<sup>2</sup>

Afyon Kocatepe University, Graduate School of Natural and Applied Sciences, Afyonkarahisar, Turkey<sup>3</sup>

Uşak University, Health Services Vocational School, Uşak, Turkey<sup>4</sup>

**ABSTRACT:** People are continuously exposed to radiation from the radon and its progenies in everyday life, which is known to be more than 50% of the total natural radiation. Since people spend more than 80% of the time in indoor environments, either at home or at work, scientists have widely conducted studies on determining the concentration of radon in indoor environments. Therefore, indoor radon levels of some houses and workplaces and the associated effective dose rates were determined in Afyonkarahisar province of Turkey. In this work, the provincial center has been assumed as divided into 4 regions by considering the rock types and tectonic structure to show the geological structure effect on indoor radon activity concentrations. The survey was carried out at 46 houses and at 28 work places using CR-39 passive nuclear track detectors four times during a one-year period. The measured values ranged from  $13 \text{ Bq.m}^{-3}$  to  $2494 \text{ Bq.m}^{-3}$ , whereas the calculated average values were in the range of  $21,75 \text{ Bq.m}^{-3}$  and  $1614,26 \text{ Bq.m}^{-3}$ . On the other hand, the calculated annual geometric mean value was  $165,57 \pm 12,86 \text{ Bq.m}^{-3}$  and the corresponding annual effective dose equivalent calculated from the geometric mean was  $4,18 \pm 0,32 \text{ mSv.y}^{-1}$  for Afyonkarahisar province.

**KEYWORDS:** Indoor radon, Annual effective dose, Nuclear track detectors, Dwellings, Afyonkarahisar.

## I. INTRODUCTION

Exposure to radon and its radioactive progeny causes a significant contribution to the average effective dose [1,2]. The epidemiological studies and the assessment of lung cancer risks have inferred the public living in dwellings with high radon concentrations may have to deal with major health problems. The radiation dose from inhaled decay products of radon causes an increased risk of lung cancer [3]. After smoking, radon is considered to be the second leading cause of lung cancer since its emitted alpha particles strike the lung tissues, resulting in lung cancer in the long term [4-8]. Radon, which has a longer half-life (3.824 days), is a colorless, odorless, and tasteless gas and therefore not detectable by human senses alone. In order to minimize the risk of lung cancer, it is essential to determine the mean of a long-time exposure of radon using a dosimeter based on alpha particle detection [9-12].

Radon and its progenies are more likely concentrated in enclosed areas such as mines, caves or dwellings especially when uranium or radium content in the soil is high [13]. For many years, the international scientific community has been studying the issue of indoor radon exposure and it is commonly believed that the level of radon concentration is strictly tied to the geological features of a specific area. Several factors can affect the radon exposure variability such as soil temperature [14], soil permeability [15], moisture state [16,17], temperature differences between the indoor and outdoor [18,19], air pressure variations [20-22], materials used for building constructions and the degree of ventilation of closed environments [23-27]. Moreover, various studies have also shown a significant variability in indoor radon levels, both on a daily and seasonal basis [28-33].

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

This article deals with the measurement of the indoor radon concentration levels and the effective dose rates of radon exposure in 46 houses and in 28 work places in Afyonkarahisar province of Turkey. The measurements were carried out seasonally using CR-39 passive nuclear track detectors four times during a one-year period. The annual effective dose received by the occupants were assessed in light of guidelines given by International Commission on Radiological Protection [7].

## II. THE GEOLOGY OF STUDY AREA

The present study area Afyonkarahisar province is in the mid-west Anatolia of Turkey (Fig. 1) which consists of lithologies related to various geological times from the Paleozoic to the Quaternary. The Paleozoic aged metamorphic rocks lay in the northwest and southeast of the city. Crystallized limestones, quartzites and schists are the main units of the Paleozoic time [34,35]. Mesozoic rocks are different in the study area. Since the northern edges are composed of detrital and carbonated rocks, Triadic-Upper Cretaceous carbonated occurrences are widespread in the Southeast. Throughout the study area, the Cenozoic units overlie in the Paleozoic and the Mesozoic rocks unconformably and they are composed of gravel and sandy fluvial sediments and, limestones and marl mixed with clay-sand-gravel-tuff in alternation. According to the seismic design code, Afyonkarahisar is located in the entire first- and second-degree earthquake zone of Turkey. The fault system in the area is named Akşehir-Simav Fault System (ASFS) trending NW–SE within the Anatolian microplate. Its width is an average of 10–30 km and the length is 550 km. The fault system is characterized by a series of grabens to horsts and their margin boundary oblique-slip normal faults [36].

## III. MATERIALS AND METHOD

### 3.1. Indoor radon activity concentrations

In this study, CR-39 solid state nuclear track detectors (SSNTDs) were used to determine the radon activity concentrations. The CR-39 detector is the diglycol carbonate ( $C_{12}H_{18}O_7$ ) and it is commonly used for the long-term measurement of the radon activity inside dwellings. A detailed description of the structure and the analysis of the detectors can be found in RADOSYS User Manual and elsewhere [37-40].

The radon activity concentration levels were measured at 46 houses and at 28 work places in Afyonkarahisar in different seasons of a year in order to study the seasonal variation of the indoor radon levels. In order to show the geological structure effect on indoor radon activity concentrations, the provincial center has been assumed as divided into 4 regions by considering the rock types and tectonic structure. The total exposure for a period of one year was obtained by carrying out four times a quarterly measurement.

Sampling was done at randomly selected houses and work places. Three dosimeters were placed at each sampling point; namely in living rooms, bedrooms and cellars/stores of the houses, and offices and stores of the work places. The dosimeters were left to record radon exposure for about 80-90 days and then taken to Sarayköy Nuclear Research and Training Center Laboratory for evaluation. After each exposure time, the detectors were subjected to chemical processing with NaOH (Radobath system) and then to track [40]. The indoor radon activity concentrations in  $Bq/m^3$  were calculated using the formula below:

$$C_{Ra} = CF \times \left( \frac{\rho_{Tracks}}{46.8} \right) \times \left( \frac{1000}{T} \right).$$

Where  $CF$  is calibration factor,  $\rho_{Tracks}$  is track density (number of tracks per  $cm^2$ ),  $T$  is the exposure time in hours. Moreover, the standard deviations were obtained using the equation as follows:

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N-1}}$$



Fig. 1: The location of Afyonkarahisar on the map of Turkey

### 3.2. Effective dose rates

The annual mean effective dose expected to be received by people in the residential places as well as workplaces due to the indoor radon and its progeny can be calculated using the following formula according to United Nations Scientific Committee on the Effects of Atomic Radiation [3]. At a certain radon concentration  $C_{Rn}$  in  $Bq.m^{-3}$ , the annual absorbed dose;  $ED$  ( $mSv.y^{-1}$ ), is usually expressed in the unit of  $mSv$  from the following relation below:

$$ED = C_{Rn} * D * F * H * T$$

Here  $C_{Rn}$  is radon concentration in  $Bq.m^{-3}$ ,  $D$  is the dose conversion factor ( $9 \times 10^{-6} mSv.h^{-1}$  per  $Bq.m^{-3}$ ),  $F$  is equilibrium factor (0.4),  $H$  is the occupancy factor (estimated 0.8 for the dwellers since dwellers spend 80% of their time indoor) and  $T$  is hours in a year (8760 h/y).

## IV. EXPERIMENTAL RESULTS

The indoor radon activity concentrations were measured using nuclear track detectors at 46 houses and at 28 work places in Afyonkarahisar province four times during a one-year period. The minimum indoor radon activity concentration was measured as  $13 Bq.m^{-3}$ , whereas the maximum measured value was  $2494 Bq.m^{-3}$ . The seasonal and regional average radon activity concentrations were calculated using the measured results for each sampling period and the annual geometric mean value of radon concentrations was determined as  $165,57 \pm 12,86 Bq.m^{-3}$  for Afyonkarahisar province. These values are shown in Table 1. Although the seasonal and regional indoor radon activity concentration values are higher than the maximum allowed limit of  $100 Bq.m^{-3}$  defined by World Health Organization [41], they are well below the limit of  $400 Bq.m^{-3}$  recommended by the Turkish Atomic Energy Authority [42] and also below the limit of  $300 Bq.m^{-3}$  by the Ref. [43] for radon in dwellings.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

	Average Radon Activity Concentrations ( $Bq.m^{-3}$ )						Annual Effective Doses ( $mSv.y^{-1}$ )	
	1 <sup>st</sup> Reigon	2 <sup>nd</sup> Reigon	3 <sup>rd</sup> Reigon	4 <sup>th</sup> Reigon	Seasonal Mean	$\pm\sigma$	Seasonal Mean	$\pm\sigma$
Summer	142,03	134,44	200,64	113,18	<b>147,57</b>	8,99	<b>3,72</b>	0,23
Autumn	98,84	150,40	171,22	88,00	<b>127,11</b>	15,76	<b>3,21</b>	0,40
Winter	218,61	314,17	274,46	168,95	<b>244,05</b>	17,22	<b>6,16</b>	0,43
Spring	124,40	196,70	163,63	89,44	<b>143,54</b>	9,46	<b>3,62</b>	0,24
<b>Annual Mean</b>	<b>145,97</b>	<b>198,93</b>	<b>202,49</b>	<b>114,89</b>	<b>165,57</b>	<b>12,86</b>	<b>4,18</b>	<b>0,32</b>

Table 1: The average and mean radon activity concentrations and corresponding annual effective doses

The associated annual effective dose equivalent of the geometric mean ( $165,57\pm 12,86Bq.m^{-3}$ ) is estimated to be  $4,18\pm 0,32mSv.y^{-1}$  for Afyonkarahisar province. Although this value is higher than both the world average annual effective dose of  $1 mSv.y^{-1}$  for radon and its decay products [44] and the value of  $2.4 mSv.y^{-1}$  for the worldwide annual effective dose from natural sources [45]. Fortunately, it is well below the action level of  $10 mSv.y^{-1}$  recommended by the Ref.[7] for radon in dwellings.

## V. CONCLUSION

The present study is the most inclusive survey carried out to determine the indoor radon activity concentrations and corresponding annual effective dose rates in Afyonkarahisar province. Moreover, it is the only study focusing on seasonal and regional effects on indoor radon concentrations in the area. The mean indoor radon activity concentration values were higher than the maximum allowed limit of  $100 Bq.m^{-3}$  defined by the WHO[41], but they are below the limit of  $400 Bq.m^{-3}$  recommended by the TAEA [42] and the limit of  $300 Bq.m^{-3}$  by the ICRP [43] for radon in dwellings.

From the seasonal point of view, the highest mean radon concentration value was obtained in winter as reported in the earlier studies of the Refs. [46-49]. This is because of poor ventilation as the doors and windows of the dwellings remain mostly closed in winter compared with the other seasons. Moreover, the outdoor pressure is much higher than the indoor pressure in winter due to very low seasonal temperature. On the other hand, mean indoor radon concentration is expected to be the lowest in summer as mentioned in many previous works. However, the similar results were not obtained in the present study, since the majority of the selected workplaces are schools and they are officially off due to summer vacation. The indoor radon concentration levels are affected by meteorological parameters such as differences in temperature and in pressure between the indoor and outdoor atmospheres.

Regional mean radon concentrations show that the values are higher in the 2<sup>nd</sup> and the 3<sup>rd</sup> regions. This is thought to depend both on the dominance of alluvial material having high porosity and permeability, and on the faults thought to have passed from the second and third regions (Fig.2). This result clearly indicates that the indoor radon activity concentration levels are strictly tied to the soil and the geological structures beneath the building and soil permeability in Afyonkarahisar province.

The annual mean effective dose equivalent of  $4,18\pm 0,32mSv.y^{-1}$  obtained in the present study carried out in Afyonkarahisar province is much higher than the value of  $1 mSv.y^{-1}$  recommended by the UNSCEAR for radon and its decay products as world average annual effective dose (UNSCEAR 2000b). Although the mean dose equivalent value obtained in winter season is very close to the action level of  $10 mSv.y^{-1}$  recommended by the ICRP (1993) for radon in dwellings, both the the annual mean value and the values of the other seasons are well below this level.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

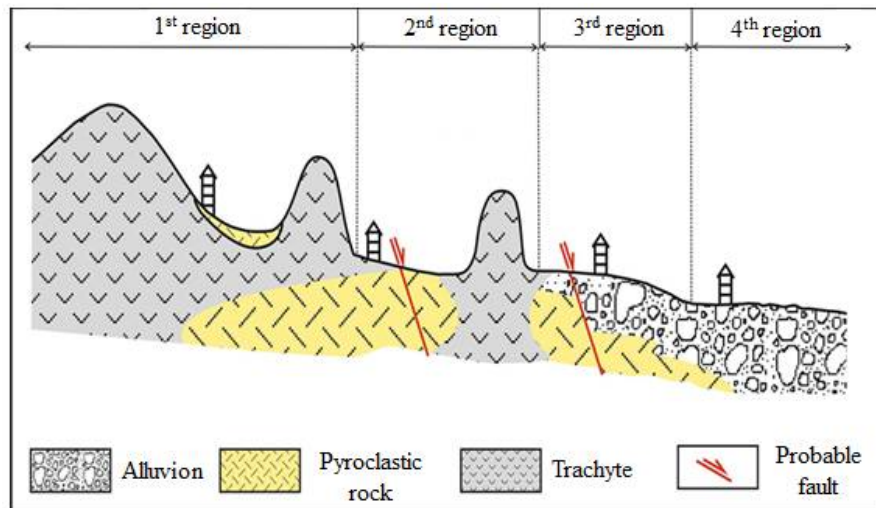


Fig. 2: Types of soil and rock in the regions

## ACKNOWLEDGEMENTS

This work is supported by Turkish Atomic Energy Authority [A5.H1.P1.06] and Afyon Kocatepe University Science Research Projects Coordination Unit with the grant numbers [16.KARİYER.157], [12.FENBİL.13] and [12.FENBİL.14]. The authors are also thankful to the director and professional staff of Health Physics Department at Sarayköy Nuclear Research and Training Center, for their valuable help in dosimetry evaluations.

## REFERENCES

- [1] Oikawa, S., Kanno, N., Sanada, T., Ohashi, N., Uesugi, M., Sato, K., Abukawa, J. and Higuchi, H (2003). A nationwide survey of outdoor radon concentration in Japan. *J. Environ. Radioact.*, [http://dx.doi.org/10.1016/S0265-931X\(02\)00097-8](http://dx.doi.org/10.1016/S0265-931X(02)00097-8).
- [2] UNSCEAR (1993). United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources, effects and risks of ionizing radiations*. Report to the General Assembly on the effects of atomic radiation. *United Nations*, New York.
- [3] UNSCEAR (2000a). United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation. In: Report to the General Assembly with Scientific Annexes, vol. I. *United Nations*, New York.
- [4] World Health Organization (WHO) (2009). Handbook on Indoor Radon: A Public Health Perspective. *WHO press*, Geneva.
- [5] Field, R.W., Steck, D.J., Smith, B.J et al C.F (2000). Residential gas exposure and lung cancer: the Iowa Radon Lung Cancer Study. *Am. J. Epidemiol.*, 151 (11), 101-102.
- [6] Bochicchio, F., Forastiere, F., Abeni, D., Rapiti, E (1998). Epidemiologic studies on lung cancer and residential exposure to radon in Italy and other countries. *Radiat. Prot. Dosim.*, 78 (1), 33-38.
- [7] ICRP (1993). Protection Against Radon-222 at Home and at Work, ICRP Publication, Annals of the ICRP Publication 65, 23(2), *Pergamon Press*, Oxford, 1-262.
- [8] Henshaw D.L., Eatough J.P., Richardson R.B (1990). Radon as a causative factor in the induction of myeloid leukaemia and other cancers in adults and children? *The Lancet*, 335, 1008-1015.
- [9] Durrani, S.A., Bull, R.K., and Haar, D. Ter., (1987). Solid State Nuclear Track Detection: Principles, Methods and Applications. ISBN: 978-0-08-020605-9, *Pergamon Press*, Oxford.
- [10] Fleischer, R.L., Price, P.B., Walker, R.M (1975). Nuclear Tracks in Solids, Principles and Applications, University of California Press, Berkeley, USA.
- [11] Khan, H.A., Qureshi, I.E., Tufail, M (1993). Passive dosimetry of radon and its daughters using solid state nuclear track detectors (SSNTDs). *Radiat Prot Dosimetry*, <https://doi.org/10.1093/oxfordjournals.rpd.a081671>.
- [12] Qureshi, A.A., Kakar, D.M., Akram, M., Khattak, N.U., Mehmood, K., Jamil, K., Khan, H.A (2000). Radon concentration in coal mines of Baluchistan. Pakistan. *J. Environ. Radioact.*, [http://dx.doi.org/10.1016/S0265-931X\(99\)00065-X](http://dx.doi.org/10.1016/S0265-931X(99)00065-X).
- [13] Khatibeh, A., Ahmad, N., Matiullah, Kenawy, M., Abumurad, K., Kullab, M., Al-Bataina, B (1997). Measurements of indoor radon concentration levels in some cities of Jordan. *Radiat. Meas.*, 28 (1-6), 589-590.
- [14] Fujiyoshi, R., Sakamoto, K., Imanishi, T., Sumiyoshi, T., Sawamura, S., Vaupotic, J., Kobal, I (2006). Meteorological parameters controlling variability of <sup>222</sup>Rn activity concentration in soil gas at a site in Sapporo, Japan. *Sci. Total Environ.*, 370 (1), 224-234. DOI: 10.1016/j.scitotenv.2006.07.007
- [15] King, C.Y., Minissale, A (1994). Seasonal variability of soil gas radon concentration in Central California. *Radiat. Meas.*, 23 (4), 683-692.
- [16] Celik, N., Poffijn, A., Cevik, U., Schepens, L (2008). Indoor radon survey in dwelling of the Kars province, Turkey. *Radiat Prot Dosimetry*, <https://doi.org/10.1093/rpd/ncm439>.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

- [17] Washington, J.W., Rose, A.W (1990). Regional and temporal relations of radon in soil gas to soil temperature and moisture. *Geophys. Res. Lett.*, 17 (6), 829-832.
- [18] Kitto, M.E (2005). Interrelationship of indoor radon concentrations, soil-gas flux, and meteorological parameters. *J. Radioanal. Nucl. Chem.*, 264 (2), 381-385. doi:10.1007/s10967-005-0725-6
- [19] Papaefthymiou, H., Mavroudis, A., Kritidis, P., (2003). Indoor radon levels and influencing factors in houses of Patras, Greece. *Journal of Environmental Radioactivity*, [http://dx.doi.org/10.1016/S0265-931X\(02\)00097-8](http://dx.doi.org/10.1016/S0265-931X(02)00097-8).
- [20] Dolejs, J., Hulka, J (2003). The weekly measurement deviations of indoor radon concentration from the annual arithmetic mean. *Radiat Prot Dosimetry*, <https://doi.org/10.1093/oxfordjournals.rpd.a006189>.
- [21] Narasimhan, T.N., Tsang, Y.W., Holman, H.Y (1990). On the potential importance of transient air flow in advective radon entry into buildings. *Geophys. Res. Lett.*, 17 (6), 821-824.
- [22] Robinson, Allen L., Sextro, Richard G (1997). Radon entry into buildings driven by atmospheric pressure fluctuations. *Environ. Sci. Technol.*, 31 (6), 1742-1748.
- [23] Al-Khateeb, H.M., Al-Qudah, A.A., Alzoubi, F.Y., Alqadi, M.K., Aljarrah, K.M., (2012). Radon concentration and radon effective dose rate in dwellings of some villages in the district of Ajloun, Jordan. *Applied Radiation and Isotopes*, <http://dx.doi.org/10.1016/j.apradiso.2012.04.009>.
- [24] Baeza, A., Navarro, E., Roldán, C., Ferrero, J.L., Juanes, D., Coebacho, J.A., Guillén, F.J (2003). Indoor radon levels in buildings in the autonomous community of Extremadura (Spain). *Radiat. Prot. Dosim.*, <https://doi.org/10.1093/oxfordjournals.rpd.a006142>.
- [25] Ulug, A., Karabulut, M.T., Celebi, N (2004). Radon measurements with CR-39 track detectors at specific locations in Turkey. *Nucl. Technol. Radiat. Prot.*, 19, 46-49.
- [26] Vaizoglu, S.A. and Güler, Ç (1999). Indoor Radon Concentrations in Ankara Dwellings. *Indoor Built Environ.*, 8, 327.
- [27] Yazar, Y., Gunaydin, T., Celebi, N (2006). Determination of radon concentrations of the Dikili geothermal area in Western Turkey. *Radiat Prot Dosimetry*, <https://doi.org/10.1093/rpd/nci321>.
- [28] Bochicchio, F., Campos-Venuti, G., Piermattei, S et al (2005). Annual average and seasonal variations of residential radon concentration for all the Italian Regions. *Radiat. Meas.*, <http://dx.doi.org/10.1016/j.radmeas.2004.12.023>.
- [29] Bossew, P., Lettner, H (2007). Investigations on indoor radon in Austria, Part I: seasonality of indoor radon concentration. *J. Environ. Radioact.*, <http://dx.doi.org/10.1016/j.jenvrad.2007.06.006>.
- [30] Magalhães, M.H., Amaral, E.C., Sachett, I., Rochedo, E.R (2003). Radon-222 in Brazil: an outline of indoor and outdoor measurements. *J. Environ. Radioact.*, [http://dx.doi.org/10.1016/S0265-931X\(02\)00175-3](http://dx.doi.org/10.1016/S0265-931X(02)00175-3).
- [31] Mihci, M., Buyuksarac, A., Aydemir, A., Celebi, N (2010). Indoor and outdoor Radon concentration measurements in Sivas, Turkey, in comparison with geological setting. *J. Environ. Radioact.*, <http://dx.doi.org/10.1016/j.jenvrad.2010.06.013>.
- [32] Moreno, V., Baixeras, C., Font, L.L., Bach, J (2008). Indoor radon levels and their dynamics in relation with the geological characteristics of La Garrotxa, Spain. *Radiat. Meas.*, <http://dx.doi.org/10.1016/j.radmeas.2008.06.003>.
- [33] Cross, F. T., Hartley, N. H., Hoffmann, W (1985). Health effects and risk from radon in drinking water. *Health Phys.*, 48(5), 649-670.
- [34] Erkan Y., Bayhan H., Tolluoğlu Ü., Aydar E (1996). Afyon Yöresi Metamorfik ve Volkanik kayaçlarının Petrografik ve Jeokimyasal İncelenmesi. TÜBİTAK Proje Raporu. YBAG-0044/DPT Projesi Raporu, Ankara. (in Turkish)
- [35] Metin S., Genç Ş., Bulut V (1987). Afyon ve dolayının jeolojisi. MTA derleme No:8103, 74s. Ankara. (in Turkish).
- [36] Koçyiğit A and Deveci Ş (2007). A N-S-trending Active Extensional Structure, the Şuhut (Afyon) Graben: Commencement Age of the Extensional Neotectonic Period in the Isparta Angle, SW Turkey. *Turkish Journal of Earth Sciences (Turkish J. Earth Sci.)*, 16, 391-416.
- [37] Abumurad, K.M., Kullab, M.K., Al-Bataina, B.A., Ismail, A.M., Lehlooh, A (1994). Estimate of radon concentrations inside houses in some Jordanian regions. *Mu'tah J. Res. Stud.*, B9 (5), 9-21.
- [38] Al-Bataina, B.A., Ismail, A.M., Kullab, M.K., Abumurad, K.M., Mustafa, H (1997). Radon measurements in different types of natural waters in Jordan. *Radiat. Meas.*, 28, 591-594.
- [39] Nikolaev, V.A., Ilic, R (1999). Etched track radiometers in radon measurements: a review. *Radiat. Meas.*, 30, 1-13.
- [40] RADOSYS (2011). RS\_Man81: User's Manual. Radosys Kft.
- [41] World Health Organization (WHO (2007)). International Radon Project Survey on Radon Guidelines, Programmes and Activities. *WHO press*, Geneva.
- [42] Turkish Atomic Energy Authority (TAEA-TAEK in Turkish acronym) (2012). Radon gas in the indoor environment. *Technical report 2012/3*, Ankara. (in Turkish)
- [43] ICRP (2009). The 2009 Recommendations of the International Commission on Radiological Protection Statement on Radon. ICRP Ref 00/902/09 (1-2).
- [44] UNSCEAR (2000b). United Nations Scientific Committee on the Effects of Atomic Radiation. Effects and Risks of Ionizing Radiations. *United Nations*, New York.
- [45] UNSCEAR (2000c). United Nations Scientific Committee on the Effects of Atomic Radiation. Ionizing Radiation: Exposure due to Natural Radiation Sources. *United Nations*, New York.
- [46] Kullab, M.K., Al-Bataina, B.A., Ismail, A.M., Abumurad, K.M., (2001). Seasonal variation of radon-222 concentrations in specific locations in Jordan. *Radiation Measurements*, [http://dx.doi.org/10.1016/S1350-4487\(01\)00186-X](http://dx.doi.org/10.1016/S1350-4487(01)00186-X).
- [47] Singh, S., Kumar, A., Singh, B., 2002. Radon level in dwellings and its correlation with uranium and radium content in some areas of Himachal Pradesh, India. *Environmental International*, 28, 97-101.
- [48] Singh, S., Mehra, R., Singh, K., (2005). Seasonal variation of indoor radon in dwellings of Malwa region, Punjab. *Atmospheric Environment*, <http://dx.doi.org/10.1016/j.atmosenv.2005.08.030>.
- [49] Sulekha Rao, N., and Sengupta, D., (2010). Seasonal levels of radon and thoron in the dwellings along southern coastal Orissa, Eastern India. *Applied Radiation and Isotopes*, <http://dx.doi.org/10.1016/j.apradiso.2009.09.026>.