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Determination of Radon Concentration by Using CR-39 Plastic Track Detectors in Dwellings of Bingöl and Mus Provinces of Turkey

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Measurements of indoor radon have a critical role in monitoring human health and safety. In this study, measurements of radon in the houses of Bingöl and Mus provinces and in their surrounding villages were performed by using CR-39 nuclear track detectors. Bingöl and Mus Provinces of Turkey have the severe terrestrial climate with hot and dry summers and cold and snowy winters for a long period. Therefore, people who spend much of their time at home have a greater risk for being exposed. The CR-39 detectors were placed in the selected 77 dwellings of Bingöl in the 2013 winter season and in 91 dwellings of Mus in 2012 winter season. Before the setup of detector, we had filled up a detailed questionnaire form to survey construction parameters and properties of the houses and living conditions of inhabitants. Detectors collected two month later were read and treated by Radosys Electronic equipment in Turkish Atomic Energy Agency Laboratory. The indoor radon concentrations in Bingöl and Mus provinces are found to vary from 43 to 348 Bq/m^3 with an average of 103 Bq/m^3 and from 25 to 604 Bq/m^{3}an average of 108 Bq/m^3, respectively.

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

INTRODUCTION

Exposure to radon in the home and workplace is one of the basic risks of ionizing radiation causing tens of thousands of deaths from lung cancer each year globally. In order to decrease this burden it is important that national authorities have methods and tools based on solid scientific evidence and sound public health policy. The public needs to raise awareness of radon risks and the means to reduce and prevent these.

Radon is a colourless, odorless radioactive gas. It is formed by the radioactive decay of small amounts of uranium that occur naturally in all rocks and soils. Essentially, 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. It also permeates small cracks in the walls and it is present in the water supply. These variations originate from differences in building materials, climate (temperature, humidity and pressure) and the geology of the area. Radon levels are generally higher at night and in the winter when windows and doors remain closed.

To observe radon, 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 appropriate for the assessment of radon exposure over long time scales and can be used for large scale surveys at moderate cost. Therefore, many countries have carried out large-scale radon surveys using passive monitoring devices, which helps to evaluate the public exposure and adopted appropriate actions for protection against radon. In this work, CR-39 nuclear track detector was used for large-scale surveys of environmental radon.

In a study, indoor radon measurements in 105 dwellings belonging to 21 villages of Muktsar and Ferozepur districts of Malwa region, Punjab, have been carried out, using LR-115 type II cellulose nitrate films in the bare mode [1].

In another work, the strong influence of geological factors on the variability of indoor radon is found in two of three geologically very different regions of South-Eastern Europe. A method to estimate the annual mean concentration when one seasonal measurement is missing is proposed. Large differences of radon concentrations in different rooms of the same house and significant difference in radon concentrations in one season comparing it to the others are noted in certain cases. Geological factors that can lead to such behaviour are discussed [2].

In addition, the seasonal indoor radon concentration in houses with different floorings, walls and roofs has been measured in Northern Rajasthan, India. The measurements were made in 100 houses using LR-115-type II plastic track detectors over four successive three-month periods (winter, spring, summer and autumn). The seasonal variation in indoor radon reveals the maximum value in winter and minimum in summer. The influences of the factors linked to building characteristics in relation to radon measurements were examined [3].

A survey was conducted to evaluate levels of indoor radon and γ-doses in 42 primary schools located in Batman, southeastern Anatolia, Turkey. Indoor radon measurements were carried out using CR-39 solid-state nuclear track detector-based radon dosimeters [4].

In a different study, radon, thoron and their decay product measurements were carried out using passive detector systems, namely the pinholes dosimeters and direct radon (Thoron) progeny sensors. These measurements were carried out in indoor environments (different dwelling types) during January-April 2013 for 90 days, in the Gogi region [5].

Radon measurements were performed in secondary schools in the Okee-Ogun area, South-west, Nigeria, by solid state nuclear track detectors (SSNTDs). About seventy CR-39 detectors were distributed in 35 high schools of the Oke-Ogun area. The tracks were counted manually at the microscope and the radon concentration was determined at the Radioactivity Laboratory, Department of Physics, University of Trieste, Trieste, Italy. The results indicate no radiological health hazard and show that radon concentrations in ground floors are higher than in upper floors [6].

For nearly 20 years the Department of Health has conducted programs to assist in the measurement and reduction of indoor radon concentrations in 186 schools located primarily in Zone 1 areas of New York State. Although many schools had few or no rooms containing radon above 148 Bq/m^3, some rooms had > 740 Bq/m^3 and remediation techniques were utilized to reduce exposure. Short-term radon measurements in the schools showed little correlation to basement and first-floor radon results from single family homes in the towns [7].

Radon monitoring by the Turkish Atomic Energy Agency began in 1984 and most major cities have accumulated base line information, except the Bingöl and Mus provinces.

Therefore, the main goal of this study is to determine ^{222}Rn activity concentration in houses and public buildings in Bingöl and Mus provinces. CR-39 nuclear trace detectors were used in these measurements.

Bingöl and Mus located in the eastern part of Turkey, are small cities. Bingöl is found on 38° 52' 59'' N, 40° 29' 34'' E coordinates. Mus is found on 38° 44' 36'' N, 41° 30' 23'' E coordinates. Bingöl and Mus have the severe terrestrial climate with hot and dry summers and cold and snowy winters for a long period. People who spend much of their time at home have a greater risk for being exposed. Therefore, the aim of our study is to assess any health risk from radon in this area.

EXPERIMENTAL

Measurements are normally performed using passive detectors. Measurements over several months are better than short-term measurements for estimating annual average radon levels. Radon levels are known to change from day to day, season to season and with the region's geology [8,9].

The plastic track etch detectors are the most common methods to measure radon levels [10,11]. For this reason, the indoor radon activity concentrations were measured by CR-39 nuclear track detectors. A total of 77 and 91 of these units were placed in houses at the center of Bingöl and Mus cities and extended to the surrounding areas. Rooms that are rarely used were not selected 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.

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 diethylene glycol bis allyl carbonate (ADC). The monomer structure is $C_{12}H_{18}O_7$ [12]. The chemical structure of the monomer is shown in Fig. 1.

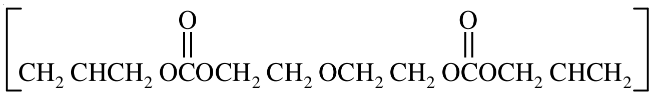


Fig. 1. Chemical structure of the monomer

The chemistry of these detectors is as follows: As seen in Fig. 1, the film structure is composed of atoms of carbon, hydrogen and oxygen. Oxygen has the largest atomic radius and more electrons in its orbits. The alpha-particles emitted from the decay of radon interact with the oxygen atoms. When an alpha particle passes through the film, it collides with the electrons of oxygen atoms and loses almost all of their energy. As seen in Fig. 2, this process leads to the positive ionization of oxygen atoms in detector film.

$$[CH_2\,CHCH_2\,OCOCH_2\,CH_2\,OCH_2\,CH_2\,OCOCH_2\,CHCH_2]$$

Fig. 2.

The track can be made visible by etching the material in strong acidic [13] or basic solutions [14]. 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, which 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 computer. The optimal use of any track detector is largely dependent on the standardization of various etching parameters, such as the bulk etch rate (Vb) and track etch rate (Vt), 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. Fig. 3 (a and b) show tracks of high and low density CR-39 detectors, respectively.

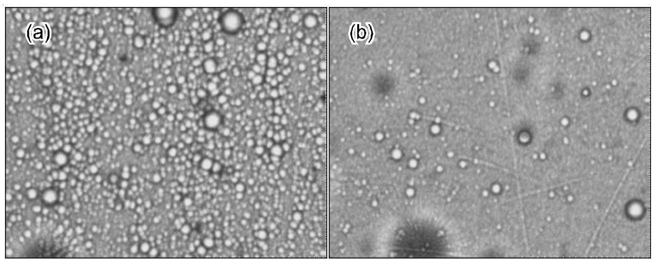


Fig. 3. (a and b). Tracks of high and low density CR 39 detectors

RESULTS AND DISCUSSION

Recently, several studies underscore the attention and severity of radon concerns. The measurements for indoor radon concentration levels were made in 77 Bingöl dwellings (Table-1) and 91 Mus dwellings (Table-2) from January to March. During the winter months, door and windows tend to be closed, concentrating on the radon counts.

TABLE-1
INDOOR RADON CONCENTRATION VALUES FOR BINGÖL

Detector No.	Avg. radon conc. (Bq/m^3)	± Bq/m^3	Detector No.	Avg. radon conc. (Bq/m^3)	± Bq/m^3
W50830	99	4.95	W51700	111	5.6
W50849	74	3.7	W51702	86	4.3
W50854	102	5.1	W51729	81	4.1
W50857	92	4.6	W51774	67	3.4
W50865	214	10.7	W51789	71	3.6
W50872	196	9.8	W51790	94	4.7
W50873	116	5.8	W51897	94	4.7
W50884	232	11.6	W51901	285	14.3
W50908	103	5.15	W51906	84	4.2
W50926	86	4.3	W51909	90	4.5
W50942	69	3.45	W51926	348	17.4
W50947	77	3.85	W51929	79	4.0
W50951	235	11.8	W51933	94	4.7
W50953	56	2.8	W51986	64	3.2
W50956	75	3.8	W52002	70	3.5
W50963	78	3.9	W52006	75	3.8
W50975	59	3.0	W52009	88	4.4
W50990	69	3.5	W52122	97	4.9
W50993	86	4.3	W52139	49	2.5
W50996	95	4.8	W52147	83	4.2
W50999	212	11	W52154	78	3.9
W51005	69	3.5	W52161	89	4.5
W51043	92	4.6	W52164	95	4.8
W51055	78	3.9	W52519	77	3.9
W51323	60	3.0	W52570	72	3.6
W51325	79	4.0	W52593	78	3.9
W51379	108	5.4	W52595	85	4.3
W51396	312	16	W52609	93	4.7
W51404	85	4.3	W52664	77	3.9
W51417	66	3.3	W52671	61	3.1
W51423	81	4.1	W52689	43	2.2
W51432	66	3.3	W52704	82	4.1
W51438	69	3.5	W52841	93	4.7
W51440	56	2.8	W52845	89	4.5
W51452	143	7.2	W52851	168	8.4
W51458	105	5.3	W52855	156	7.8
W51474	68	3.4	W52874	79	4.0
W51489	162	8.1	W52880	76	
W51677	102	5.1			

TABLE-2
INDOOR RADON CONCENTRATION VALUES FOR MUS

Detector No.	Avg. radon conc. (Bq/m^3)	± Bq/m^3	Detector No.	Avg. radon conc. (Bq/m^3)	± Bq/m^3
W50818	72	3.6	W50962	111	5.6
W50824	153	7.7	W50969	44	2.2
W50826	71	3.6	W50970	43	2.1
W50827	199	9.9	W50973	78	3.9
W50829	94	4.7	W50974	144	7.2
W50835	44	2.2	W50980	156	7.8
W50838	59	3	W50981	46	2.3
W50844	48	2.4	W50987	102	5.1
W50845	59	3	W50989	49	2.4
W50846	68	3.4	W50991	355	17.8
W50848	115	5.7	W50997	93	4.7
W50853	83	4.2	W50998	228	11.4
W50856	39	1.9	W51004	108	5.4
W50863	71	3.6	W51006	44	2.2
W50870	43	2.1	W51007	209	10.5
W50871	49	2.5	W51008	46	2.3
W50874	91	4.5	W51009	95	4.8
W50875	73	3.7	W51010	129	6.5
W50878	40	2	W51013	36	1.8
W50881	248	12.4	W51016	75	3.7
W50885	418	20.9	W51020	71	3.6
W50890	59	3	W51024	46	2.3
W50891	43	2.2	W51027	53	2.7
W50893	49	2.5	W51028	63	3.2
W50897	34	1.7	W51029	132	6.6
W50900	57	2.9	W51033	112	5.6
W50901	56	2.8	W51034	44	2.2
W50902	95	4.7	W51035	332	16.6
W50906	63	3.2	W51036	35	1.7
W50909	90	4.5	W51044	101	5.1
W50911	68	3.4	W51046	172	8.6
W50912	87	4.4	W51047	44	2.2
W50919	66	3.3	W51049	77	3.8
W50923	220	11	W51051	67	3.3
W50925	604	30.2	W51052	243	12.2
W50928	72	3.6	W51054	51	2.5
W50929	72	3.6	W51060	74	3.7
W50934	156	7.8	W51061	107	5.4
W50937	235	11.8	W51064	25	1.3
W50943	67	3.3	W51070	32	1.6
W50944	71	3.6	W51072	436	21.8
W50946	47	2.4	W51074	181	9.1
W50948	50	2.5	W51079	201	10.1
W50954	82	4.1	W51080	66	3.3
W50955	74	3.7	W51081	126	6.3
W50959	72	3.6			

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 [15].

The World Health Organization [16] has suggested that home owners 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 [17], which has been the USA standard for many years [18]. The upper limit value of radon by TAEK is 400 Bq/m^3. The average indoor radon concentration values for houses in these places were 103 Bq/m^3 for Bingöl and 108 Bq/m^3 for Mus. The highest average indoor concentration was 348 Bq/

m^3 for Bingöl and 604 for Mus. The lowest average indoor concentration was 43 Bq/m^3 for Bingöl and 25 Bq/m^3 for Mus. 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 [19]. Their suggestions are as follows:

• An indoor radon decay product equilibrium factor (EF) of EF = 0.4

• A radon effective dose coefficient factor (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. 1:

$$D = (C_{Rn}) \times (EF) \times (EDCF) \times (OF) \times (T) \quad (1)$$

$D = [103\ Bq/m^3] \times [0.4] \times [9 \times 10^{-9}\ (Sv)/(Bq\ h\ m^{-3})] \times [0.8] \times [8760\ (h)]$

D = 2.59 mSv for Bingöl and

$D = [108\ Bq/m^3] \times [0.4] \times [9 \times 10^{-9}\ (Sv)/(Bq\ h\ m^{-3})] \times [0.8] \times [8760\ (h)]$

D = 2.72 mSv for Mus

The calculated value for average annual effective dose for houses in Bingöl and Mus was 2.59 mSv and 2.72 mSv, respectively. The calculated values of average annual effective dose for the study area varied from 1.08 mSv to 8.75 mSv. The average annual effective dose values, 2.59 and 2.72 mSv, is less than even the lower limit of suggested action level (3-10 mSv). Therefore, the calculated values for average annual effective dose of 2.59 mSv and 2.72 mSv 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 [20]. Further, the average annual effective dose of 2.59 mSv and 2.72 mSv are more than the accepted value of 1.3 mSv set by UNSCEAR in1993 [21] 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.

These winter radon measurements are expected to be higher than those in other seasons of the year, especially in poorly ventilated houses. The distribution of indoor radon levels among 77 houses in Bingöl and the distribution of indoor radon levels among 91 houses in Mus are shown in Fig. 4a and 4b.

Radon concentrations in 2.6 % of houses in Bingöl and in 26.4 % of houses in Mus ranged between 0 and 50 Bq/m^3.

72.7 % of them in Bingöl and in 41.8 % of them in Mus ranged between 51 and 100 Bq/m^3.

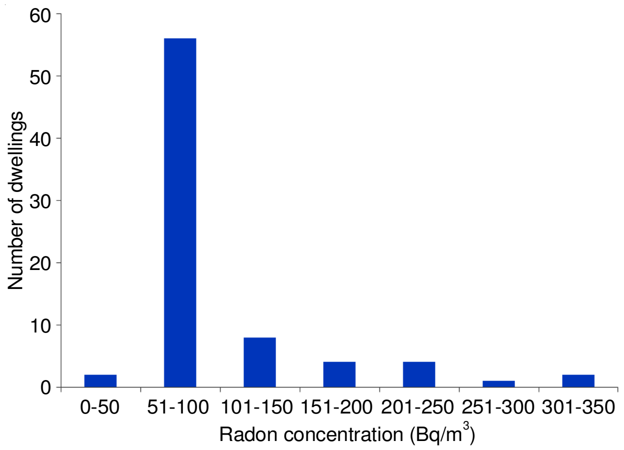
10.4 % of them in Bingöl and in 12.1 % of them in Mus ranged between 101 and 150 Bq/m^3.

5.2 % of them in Bingöl and in 6.6 % of them in Mus ranged between 151 and 200 Bq/m^3.

5.2 % of them in Bingöl and in 6.6 % of them in Mus ranged between 201 and 250 Bq/m^3.

1.3 % of them in Bingöl and in 1.1 % of them in Mus ranged between 251 and 300 Bq/m^3.

2.6 % of them in Bingöl and in 2.2 % of them in Mus ranged between 301 and 350 Bq/m^3.



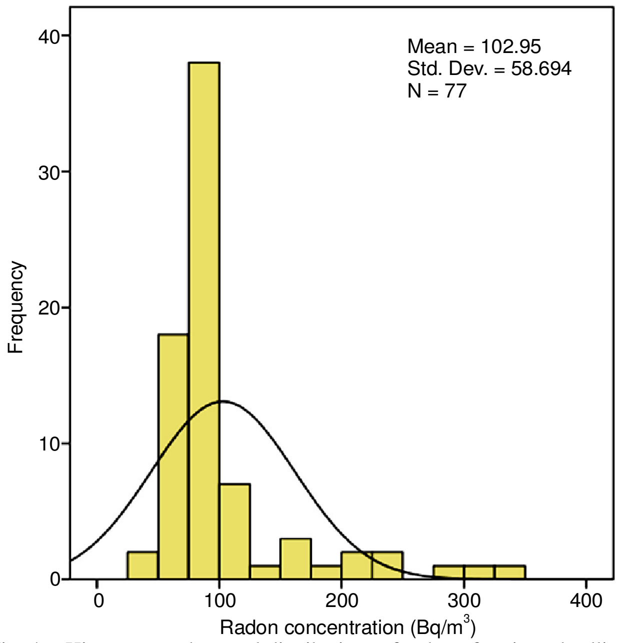


Fig. 4a. Histogram and normal distributions of radon of various dwellings in Bingöl province

2.2 % of them in Mus ranged between 351 and 400 Bq/m^3.

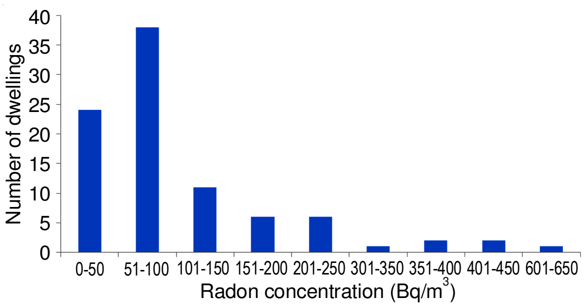
1.1 % of them in Mus ranged between 600 and 650 Bq/m^3.

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 (IBM Statistics).

The results of this statistical analysis are shown in Tables 3 and 4. Radon action concentration was chosen as dependent variable. These tables illustrate the relationship between Bingöl and Mus radon concentrations. P value is greater than 0.01. So, there was not significant relationship between Bingöl and Mus radon concentrations.

TABLE-3
DESCRIPTIVE STATISTICS OF BINGÖL

Radon concenration (Bq/m^3)	Mean	Std. deviation	N
50-100	78.3390	13.00744	59
100-150	112.1429	14.57656	7
150-200	170.5000	17.69184	4
200-360	262.5714	53.002695	7



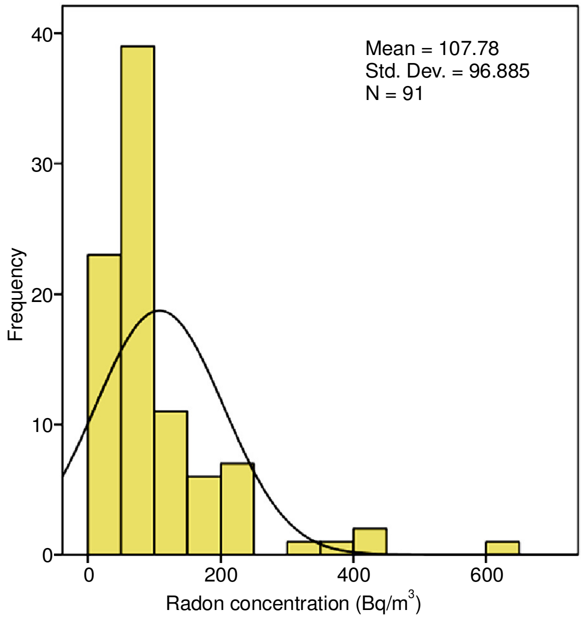


Fig. 4b. Histogram and normal distributions of radon of various dwellings in Mus province

TABLE-4
DESCRIPTIVE STATISTICS OF MUS

Radon concenration (Bq/m^3)	Mean	Std. deviation	N
0-50	42.487	6.217	24
50-100	72.507	11.984	38
100-150	117.043	13.824	11
150-200	169.465	18.120	6
200-250	226.333	17.295	7
250-650	429.134	106.846	5
Total	107.794	96.913	91

Table-5 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 Bingöl and Mus locate middle values in the those reported values.

TABLE-5
COMPARISON OF PRESENT RESULTS WITH OTHER RESULTS IN VARIOUS LOCATIONS IN TURKEY

Country	Mean radon concentration (Bq/m^3)	Country	Mean radon concentration (Bq/m^3)
Igdır	87	Tekirdag	87
Istanbul	50	Manisa	97
Izmir	70	Kilis	50
Karabük	131	Osmaniye	51
Batman	84	Sivas	89
Giresun	130		

The reported values of indoor radon concentration for Bingöl and Musin present study are lower than the radon action level 200-600 Bq/m^3 as proposed by ICRP [22] but these values are slightly larger than the new reference value(100 Bq/m^3) set by WHO.

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