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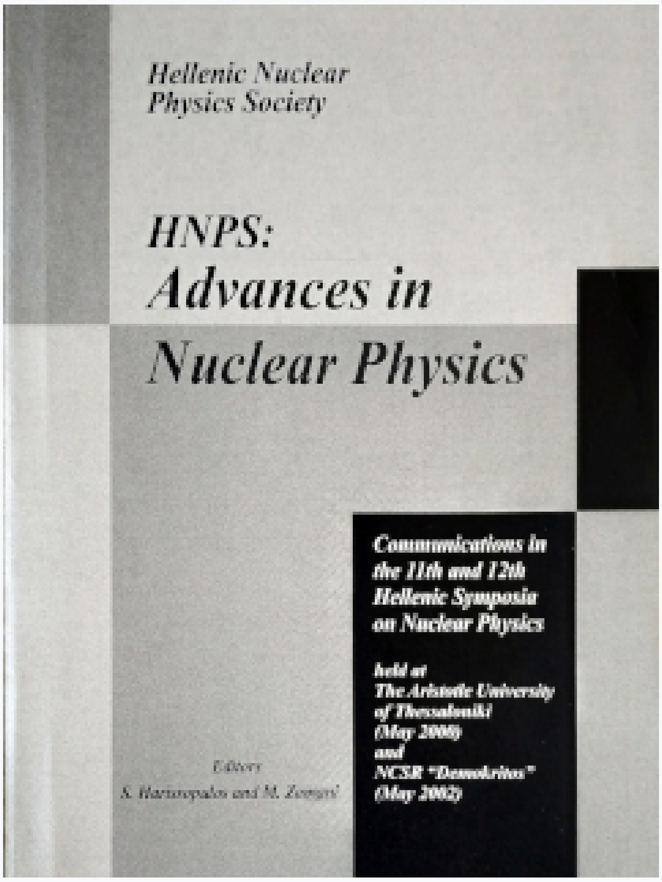

A survey of 222Rn concentrations in dwellings of the town of Metsovo in North-western Greece

K. G. Ioannides, K. C. Stamoulis, C. A. Papachristodoulou

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A survey of ^{222}Rn concentrations in dwellings of the town of Metsovo in North-western Greece.

K. G. Ioannides, K. C. Stamoulis and C. A. Papachristodoulou
Nuclear Physics Laboratory, The University of Ioannina, 451 10 Ioannina, Greece.

Abstract_ A radon survey has been carried out of indoor radon concentrations in dwellings located in the town of Metsovo, in north-western Greece. To measure indoor radon concentrations, CR-39 detectors were installed in randomly selected houses and were exposed for about 3 months, during summer and winter. Also gamma spectroscopy measurements of the soil's radium content were performed. The indoor radon concentration levels varied from 17.6 to 750.4 Bq m^{-3}, while the radium concentration of soil varied from 4.9 to 97.1 Bq m^{-3}. Seasonal variation of the radon levels and the influence of house features and soil are discussed.

INTRODUCTION

Radon is an inert radioactive gas produced by the decay of uranium that occurs naturally in Earth's crust. Outside air contains very low levels of radon, but indoors the gas accumulates to higher concentrations. When radon daughter radionuclides are formed, they are electrically charged and can attach themselves to tiny dust particles in the air. The radiation emitted by inhaled particles can not travel far enough to reach cells in organs other than the lung, so it is likely that lung cancer is the only significant health hazard posed by radon. Several studies have linked the high incidence of lung cancer in miners with radon exposure, leading to concerns that exposure to the gas in homes could cause cancer (BEIR VI 1999).

Since the early eighties, the inhabitants of the town of Metsovo (population 3000) in north-western Greece were diagnosed to suffer from endemic pleural calcification, which is a typical ailment caused by exposure to asbestos (Bazas et al. 1981, Constantopoulos et al 1985). Also an unusually high frequency of malignant pleural mesothelioma was reported for the same area (Constantopoulos et al 1987, Langer et al 1987). The two observations were attributed to asbestos contained in a material called «luto soil», which was extensively used for whitewashing homes, until 1960.

It is known that if airborne asbestos fibres are inhaled, they lodge in the lungs and lead to variety of diseases including lung cancer. The reports for unusual lung cancer cases in Metsovo, prompted the present investigation, aiming at the survey of indoors radon, which is also considered as a carcinogen.

MATERIALS AND METHODS

Radon survey

The area of Metsovo in north-western Greece is an alpine mountain region featuring high tourist qualities with low urbanisation and industrialisation. The number of dwellings in Metsovo is approximately one thousand and two hundred. The detectors were placed in the living rooms of randomly selected typical for the region houses, away from windows and doors to avoid draughts. The radon screening was implemented in two exposure periods, during summer and winter. The start date of the summer exposure period was in the first week of June 1998. The start date of winter period was in the first week of December 1998. The measurements of the survey were performed with passive radon dosimeters utilizing CR-39 solid state nuclear track detectors. The duration of exposure was three months. The detectors were installed in the same week and in the end of exposure periods were removed in the same week. There were no difficulties with participations or access to houses because the inhabitants of Metsovo were sensitised by the asbestos problem in the area and were willing to participate in the investigation.

Radon measurements

The measurements of radon concentrations were carried out with CR-39 solid state nuclear track detectors (Ilic and Sutej 1997). The detectors were placed in small plastic cylindrical containers (5 cm height, 3 cm diameter) covered with a cloth of 0.5 mm mesh. The detection arrangement was calibrated in the radon calibration chamber of the NRPB laboratories in Didcot, UK.

Following exposure, the CR-39 detectors were etched in a solution of 7N NaOH at 80^0C for 8 h. Then they were measured using a semi-automatic measuring arrangement, employing a microscope - video camera - frame grabber -computer chain. The magnification of the objective lens was 4X. The magnification of the microscope-computer system, which depends on the image dimensions on the computer screen varies in the range of 80X to 200X The tracks to activity conversion factor was (210 ± 15) Bq m^{-3}/ tracks cm^{-2} d.

The computer program TRACKA (Ioannides 1995) was used to count the number of tracks per optical field by counting the picture elements (pixels) with grey-scale values specified previously. For the purpose of alpha-tracks measurements a 640X480 resolution is chosen. The dynamic range of the image is converted to 8-bit (256 shades) gray scale. The dynamic range (bit-depth) determines the number of colors or shades of gray (gray scale) that can be represented in a digital image. The specific colors used form the image's palette. Since the smallest unit of data stored in a computer is the bit, the dynamic range is a measurement of the number of bits used to represent each pixel in an image (and hence the maximum number of colors or shades of gray in its palette). In a 24-bit image each pixel can represent one of 2 to the power of 24 (more than 16 million) possible colors. Eight bits are devoted to recording each of the three additive primary colors; red, green and blue. In an 8-bit image each pixel represents one of 2 to the power of 8 (or 256) possible colors or shades of gray The specific colors used in a digital image form the image's palette.

To automatically count the number of tracks per optical field, code TRACKA calculates the picture elements (pixels) with certain grey-scale values, specified previously. Before the enumeration of the tracks, a calibration procedure is carried out in order to correlate the average number of pixels of a track image with the gray scale values. In this procedure the enumeration of tracks is manually performed and the tracks are counted with the help of the (mouse) cursor. Then the gray scale values of individual pixels of a number of tracks are summed and an average gray scale sum (AGS) value is chosen to represent the track. Then the corresponding gray scale sum (GS) value is computed for the all the tracks of the optical field. The number of tracks is computed dividing the GS value of the whole optical field (which contains all tracks) by the one track AGS value. For the computation of the GS values limits on pixel GS values can be imposed to define

Before the enumeration of the tracks, a calibration procedure was carried out in order to correlate the average number of pixels of a track image with the gray scale values.

Gamma spectroscopy

To examine the radium content of construction materials such as building stones and also the radium content of soil, gamma spectroscopy measurements were performed. First the samples were dried and then measured in the standard geometry of 0.4 L and 1 L (Marineli container) with a 1.9 keV resolution (for the 661.65 keV line of ^{137}Cs), 22% efficiency, intrinsic Ge detector. The detector was shielded against background radiation with 5 cm lead.

Standard electronics were used and the spectra, accumulated in 2048 channels, were stored for analysis in a IBM compatible computer. The detector was calibrated for efficiency with a standard ^{152}Eu source. The accumulation of a spectrum with adequate statistics required 1000 to 20000 s. To determine the radium content of the samples, the peak at 186.2 keV was identified and analysed.

RESULTS

Radon measurements

Radon measurements are contained in Table 1 and presented graphically as a frequency distribution in Figure 1. The theoretical frequencies of the log-normal distribution were also plotted on the frequency distribution on the classes in Figure 1. The log-normal distribution was computed by a least squares fitting procedure ($\div^2$=3.53), using the Levenberg-Marquardt algorithm.

The statistics of the measurements are summarised in Table 2. Frequency plots for measurements performed during winter and summer months are presented in Figure 2. The measurements are also presented as histogram plots displaying average radon concentrations as they are categorised by season, floor level, and house construction style (Figures 3 and 4). The corresponding mean values for each category were compared for significance with the Student's t test and results are presented in Tables 3 and 4. The only statistically significant differences in radon concentrations were found between houses of modern construction and old construction and also between concentrations measured in summer and winter in modern houses.

The radon concentrations, which were measured during winter and were characterized by a considerable variation, displayed a decreasing trend with floor level (Figure 3). They varied from a mean value of 385 ± 288 Bq m^{-3} for the apartments on ground floor to the mean value of 68 ± 23 Bq m^{-3} for the apartments at the third floor. The decreasing trend in the winter radon concentrations with the floor level may be attributed to increasing air exchange rates with floor levels. Recently, this behaviour was measured and modeled by Man and Yeung (1999), who also found that air exchange rates increase with floor levels, whilst the indoor and outdoor radon concentrations decreased. These authors using a model utilizing a simple mass balance equation calculated the indoor radon concentration inside a room on each of level and the results agreed well with measurements.

Considering the low temperatures that frequently prevail during winter in the area of Metsovo, the variation of radon concentration values, which may be attributed to different habits in refreshing the air indoors, is such that no statistically significant difference is found between radon and floor level. However, radon concentrations during summer vary to a lesser extent around a mean value of 154 ± 40 Bq m^{-3}. This observation may be explained by the fact that during summer, opened windows help to increase the air exchange destroying the correlation to floor level.

Radon concentrations for houses of different construction are presented in Figure 4. Indoor radon concentrations in recently constructed buildings (Figure 4A) are characterized by higher mean values during summer. The mean value of the summer radon concentration is 165 ± 44 Bq m^{-3}, while the corresponding value during winter is 115 ± 56 Bq m^{-3}. Reinforced concrete and bricks constructed the modern houses, while old houses were built with stones and wood. In winter the mean value of radon concentrations in old houses (Figure 4B) was 230 ± 203 Bq m^{-3}. To exclude the possibility that the stones used for the construction of old houses had a high uranium/radium content, we measured the radium concentration in stones with gamma spectroscopy. As a result of these measurements, the radium concentration of the stones was determined 8 ± 3 Bq kg^{-1}.

Mean radon concentrations values measured in the old and the new houses during summer were estimated 135 ± 25 Bq m^{-3} and 165 ± 44 Bq m^{-3} respectively. The difference found in these values is not statistically significant.

Radium in soil measurements

Since the indoor radon concentrations were measured to be rather high, with a mean value exceeding the US Environmental Protection Agency (EPA) action level of 148 Bq m^{-3}, we performed gamma spectroscopy measurements to measure the radium content of soil samples, collected from soil surrounding selected houses in Metsovo. The results of these measurements are shown in Table 5. From these results we ascertain that the source of indoor radon concentrations in the town of Metsovo (mean = 170 ± 132 Bq m^{-3}) is soil, with its relatively high radium content (mean =50 ± 24 Bq kg^{-1}). Available data from soil radium measurements performed in Belgium by Tondeur et al (1996) show a similar correspondence of soil radium content about 40 Bq kg^{-1} to indoor radon concentrations more than 250 Bq m^{-3}.

DISCUSSION AND CONCLUSIONS

Radon exposure is known to cause lung cancer in miners and elevated radon levels in houses raises concerns that domestic exposure might account for a percentage of lung cancer incidence in the general population. Using exposure to dose conversion factors (ICRP, 1994), the average annual effective doses due to radon exposure to the inhabitants of Metsovo town are 0.3 to 12.9 mSv, corresponding to radon exposures from 17.6 to 750.4 Bq m^{-3}, for a full year (7000 h). This exposure represents a life time relative risk (LRR), which describes the relative increment in lung cancer risk resulting from exposure to indoor radon from 1 to 4, depending on the smoking status, gender and the model used (BEIR VI, 1999).

The exposure of the inhabitants of Metsovo asbestos fibres has caused pleural calcifications among the inhabitants of the town of Metsovo, to a percentage of 46%. Also the incidence of malignant mesothelioma was reported to reach an extraordinary magnitude, about 280 times the expected value (Constantopoulos et al 1985, Constantopoulos et al 1987, Langer et al. 1987). However, the incidence of other lung cancer cases in Metsovo was not reported in the previous studies. To elucidate the issue of lung cancer mortality, other than from malignant mesothelioma, we resorted to the data of the register office of the town of Metsovo, where we enumerated the recorded deaths attributed to lung cancer in the last three decades. From this search, it was found first that the annual lung cancer mortality in the last decade in Metsovo is 60.9 deaths per 10^5 and second that the deaths from lung cancer were 35.2% of the total cancer deaths. The 60.9 deaths per 10^5 lung cancer mortality is not exceptionally high, since higher incidence rates have been observed elsewhere (e.g. the incidence rate in males of the Varese province, Northern Italy (Russo et al 1997) is 82.3 per 100000, among the highest worldwide). However the ratio of lung cancer to total cancer deaths (35.2%) is high, almost 3 times greater than that cited for the world total cases (12.8%). This ratio should be attributed to the asbestos exposure.

Inferring synergy of radon and asbestos exposure from the results of the present work is not possible. Although there are the suggestions for synergy coming from laboratory investigations these experiments were performed at unrealistically high concentrations. We end this report emphasising our agreement with the conclusions of other studies (Stidley and Samet 1993, Greenland and Robins 1994, BEIR VI 1999), which advocate that due to inherent limitations, the ecologic studies are not considered to be an appropriate basis for quantitatively estimating lung-cancer risk associated with radon exposure. The ecologic regression coefficients may bias (in our work the lung cancer data are effected by asbestos exposure) and the only way to estimate the health consequences of radon exposure is by case-control studies.

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FIGURE CAPTIONS

Figure 1. Frequency distribution of ^{222}Rn activity concentrations measured in houses in the town of Metsovo and theoretical frequencies plotted as the log-normal distribution (dashed line).

Figure 2. Frequency distributions of ^{222}Rn activity concentrations measured in houses in the town of Metsovo during summer and winter months.

Figure 3. Winter-summer variations of average ^{222}Rn activity concentrations with floor level.

Figure 4. Winter-summer variations of average ^{222}Rn activity concentrations with floor level for different house constructions. A. Modern house construction (concrete/bricks). B. Old construction (stone/wood).

ble 1. Measurements of radon concentration in houses ($Bq\ m^{-3}$). Values are presented with standard error.

easurement number	Radon concentration ($Bq\ m^{-3}$) ± S.E.	Season[1]	Floor level[2]	Construction[3]	Attached to cliff[4]
1	285 ± 37	s	3	modern	no
2	42 ± 21	w	3	modern	no
3	161 ± 9	s	2	modern	no
4	46 ± 11	w	2	modern	no
5	77 ± 11	w	1	modern	no
6	57 ± 19	w	1	old	no
7	163 ± 4	s	1	modern	no
8	121 ± 15	s	2	old	no
9	98 ± 17	w	2	old	no
10	215 ± 7	w	1	old	no
11	103 ± 9	s	2	modern	no
12	144 ± 16	w	2	modern	no
13	108 ± 15	s	2	old	no
14	114 ± 33	w	2	old	no
15	128 ± 22	w	1	old	no
16	131 ± 35	s	1	old	yes
17	132 ± 15	s	2	modern	no
18	150 ± 24	w	2	modern	no
19	221 ± 40	w	1	modern	no
20	18 ± 24	w	2	old	no
21	138 ± 10	s	2	modern	no
22	43 ± 14	w	2	modern	no
23	164 ± 13	s	0	old	yes
24	622 ± 41	w	0	old	yes
25	470 ± 41	w	0	old	yes
26	103 ± 8	w	2	old	no
27	148 ± 18	s	2	old	no
28	750 ± 51	w	2	old	no
29	273 ± 21	w	1	old	yes
30	178 ± 23	s	2	modern	no
31	167 ± 30	w	2	modern	no
32	187 ± 58	w	1	old	no
33	161 ± 11	s	1	old	no
34	202 ± 25	s	1	modern	no
35	85 ± 17	w	1	modern	no
36	96 ± 12	s	2	old	no
37	73 ± 22	w	2	old	no
38	234 ± 23	w	1	old	no
39	308 ± 29	w	1	old	no
40	70 ± 32	w	1	old	no
41	141 ± 19	s	3	modern	no
42	82 ± 27	w	3	modern	no
43	178 ± 27	w	1	old	no
44	135 ± 47	w	2	modern	no
45	146 ± 34	s	2	modern	no
46	173 ± 54	w	2	modern	no
47	189 ± 15	s	2	modern	no
48	182 ± 9	w	2	modern	no
49	102 ± 8	w	2	modern	no
50	418 ± 43	w	1	old	yes
51	154 ± 19	s	3	modern	no
52	81 ± 18	w	3	modern	no
53	155 ± 29	s	0	old	yes

54	64 ± 21	w	0	old	yes
55	153 ± 6	s	2	modern	no

[1] s represents summer and w winter.
[2] «0» indicates apartments on ground level, «1» apartments on the fist floor, "2» apartments on the second floor, etc.
[3] Houses built with stones and wood are characterised as of «old» construction, while houses built with concrete and bricks are characterised as of «modern» construction.
[4] Some apartments mostly of old construction are attached to a cliff of a hill from one side.

Table 2. Statistical data for indoor radon concentrations in 55 houses in the town of Metsovo.

Parameter	Indoor radon ($Bq\ m^{-3}$)
Arithmetic mean	169.7
Standard deviation	131.7
Minimum	17.6
Maximum	750.4
Range	732.8
Median	146.4
Skewness	2.66
Kurtosis	8.53

Table 3. Student's t test statistics (p = 0.05) are presented for houses of old and new construction, during summer and winter. When no significant differences between radon concentrations in two different house groups is found, the H_0 hypothesis that there is no difference between the mean values, is "accepted". If the opposite case is true, the H_0 hypothesis is "rejected". In the last row of each table, t test values (p = 0.05) for summer-winter radon concentration comparisons for the same floor level, are presented.

Old construction							
	Floor Level	*0*	*1*	2	*0*	*1*	2
Summer	*0*	-	0.59	2.07	-	accepted	accepted
	1		-	1.18		-	accepted
Winter	*0*	-	1.48	0.86	-	accepted	accepted
	1		-	0.13		-	accepted
Summer-Winter		-0.86	-0.71	-0.51	accepted	accepted	accepted

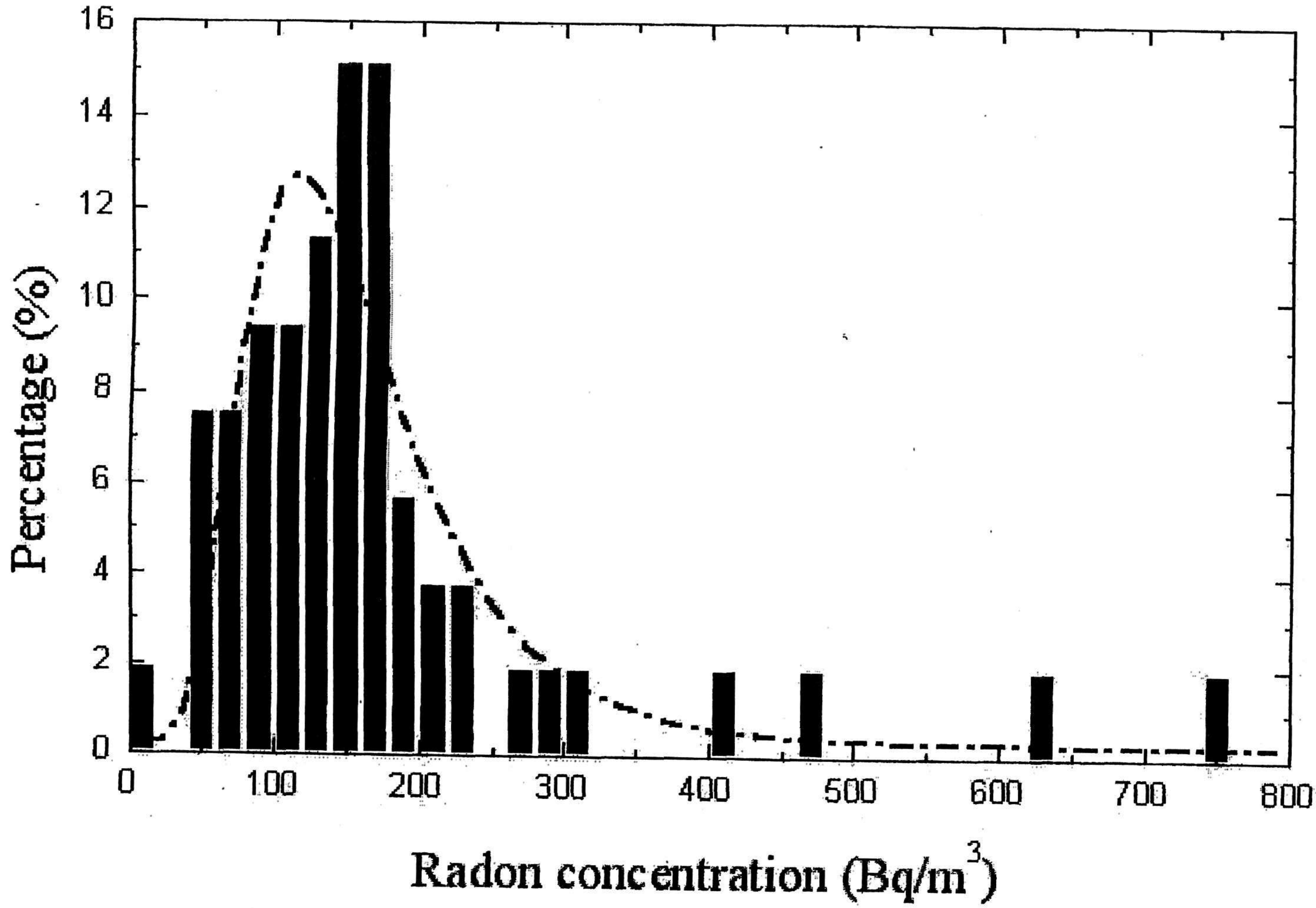
Modern construction							
	Floor Level	*1*	2	*3*	*1*	2	*3*
Summer	*1*	-	1.35	-0.14	-	accepted	accepted
	2		-	-1.21		-	accepted
Winter	*1*	-	0.01	1.00	-	accepted	accepted
	2		-	1.71		-	accepted
Summer-Winter		0.72	1.05	2.13	accepted	accepted	accepted

Table 4. Student's t test statistics (p = 0.05) for all apartments, according to age of construction. «Accepted» stands for the acceptance of the H_0 hypothesis (See also legend of Table 3).In the last row, t test values (p=0.05) for houses of the same construction style are presented.

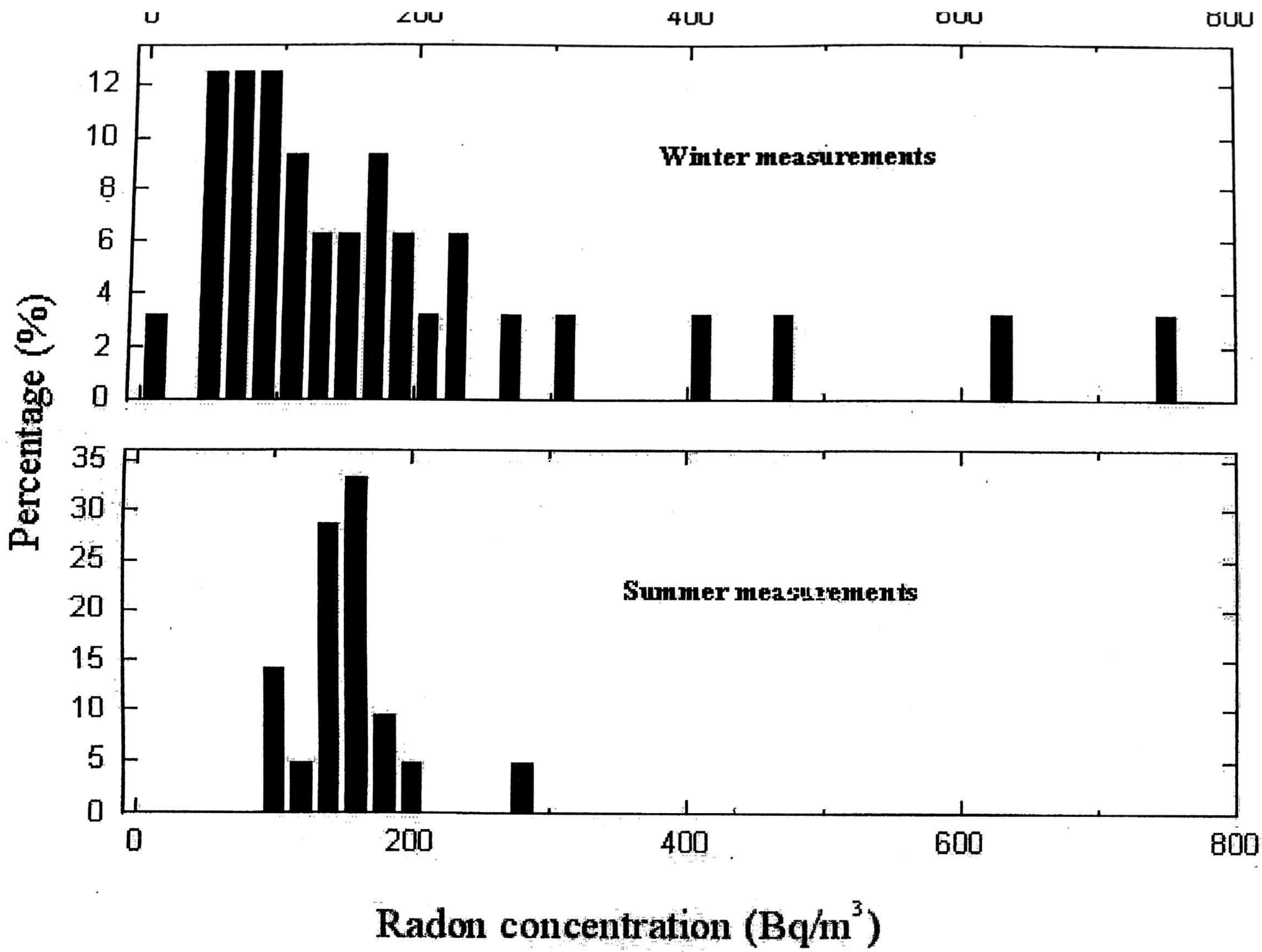
		All apartments			
	Construction	*modern*	*old*	*modern*	*old*
Summer	*modern*		1.64		accepted
Winter	*modern*		-2.07		rejected
Summer-Winter		2.47	-1.27	rejected	accepted

able 5. Statistical data for soil radium concentrations in 10 samples from the town of Metsovo.

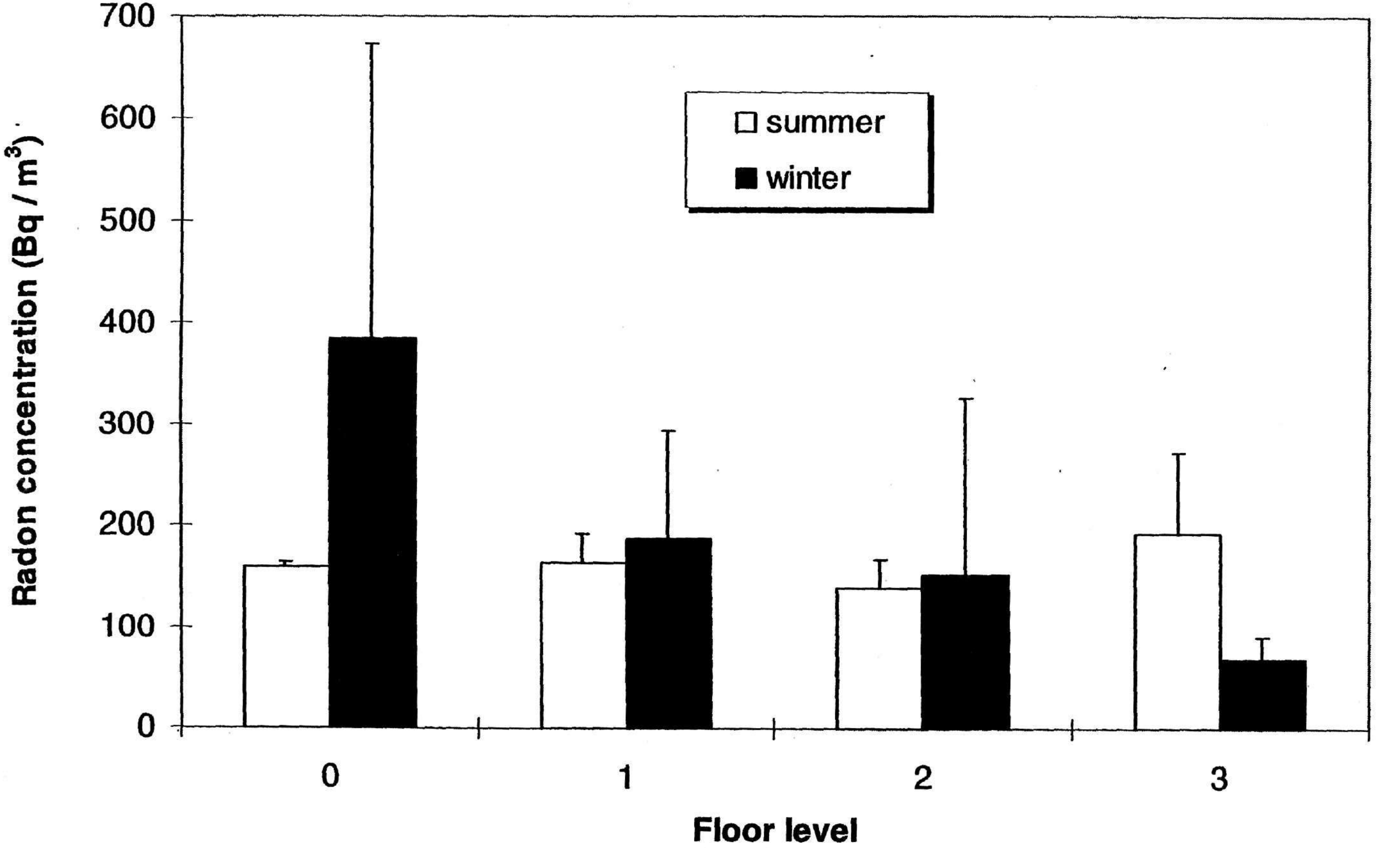
Parameter	Radium Concentration ($Bq\ m^{-3}$)
Arithmetic mean	49.8
Standard deviation	24.01
Minimum	4.9
Maximum	97.1
Range	92.2
Median	146.4
Skewness	.23
Kurtosis	1.76

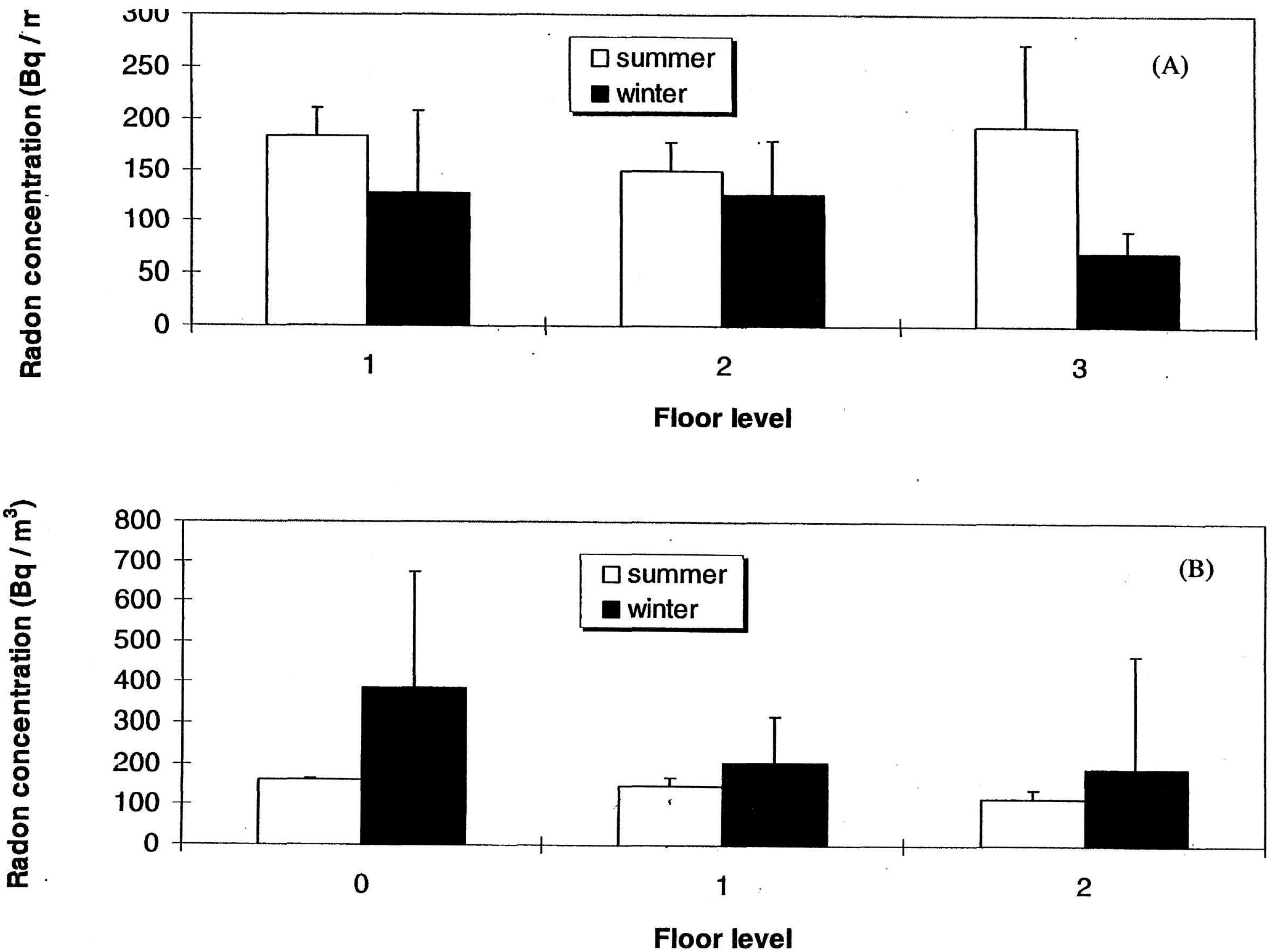


Percentage (%)
0
2
4
6
8
10
12
14
16
0
100
200
300
400
500
600
700
800
Radon concentration (Bq/m3)



Winter measurements
Summer measurements
Percentage (%)
Radon concentration (Bq/m3)
0
200
400
600
800
12
10
8
6
4
2
0
35
30
25
20
15
10
5
0


700
600
500
400
300
200
100
0
Radon concentration (Bq / m3)
summer
winter
0
1
2
3
Floor level



(A)
summer
winter
Radon concentration (Bq / m
300
250
200
150
100
50
0
1
2
3
Floor level
(B)
summer
winter
Radon concentration (Bq / m³)
800
700
600
500
400
300
200
100
0
0
1
2
Floor level