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Annual average and seasonal variations of residential radon concentration for all the Italian Regions

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Abstract

A representative National Survey to evaluate the exposure to natural sources of ionizing radiation in dwellings was conducted in all the 21 Italian Regions from 1989 to 1998, and the complete results are reported in this paper. Radon concentration was measured for two consecutive 6-month periods (generally covering the spring–summer and autumn–winter seasons) in one room, usually the main bedroom, of each surveyed dwelling. Validated radon concentration measurements were obtained for

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a total of 5631 dwellings, distributed in 232 towns (all the 50 towns with more than 100,000 inhabitants and 182 randomly sampled smaller towns). The national average, weighted by the population of each Region, of the annual radon concentration is 70 Bq m^{-3}, the geometric mean is 52 Bq m^{-3}, and the geometric standard deviation is 2.1. The fraction of dwellings with a radon concentration exceeding the reference levels of 150, 200, 400, and 600 Bq m^{-3} are 7.7%, 4.1%, 0.9%, and 0.2%, respectively. Regional averages ranged from about 25 Bq m^{-3} to about 120 Bq m^{-3}. The uncertainty of regional values can be relevant in the case of small Regions, where few small towns were sampled, however such uncertainties do not affect national values significantly. A log-normal model underestimates the fraction of dwellings with high radon concentration and needs to be adjusted to obtain a better fitting. Two complete 6-month measurements were obtained for 4742 dwellings. The regional values of the geometric mean and of the geometric standard deviation of the winter/summer ratio ranged from 0.81 to 2.58 and from 1.32 to 1.88, respectively. The corresponding national values were 1.23 and 1.71, respectively. These results and their implications are discussed in the paper.

Keywords: Indoor radon; Representative survey; LR 115; Log-normal distribution; Seasonal variations

1. Introduction

Performing a national representative survey in dwellings has been a fundamental step of radon programs in several countries, in order to obtain the necessary knowledge for adequate future actions (e.g., Langroo et al., 1991; Marcinowski et al., 1994; Swedjemark et al., 1993; Wrixon et al., 1988). Owing to radon concentration temporal variations, a 12-month total period of measurement is generally considered the best estimate of the average value. Shorter measurement periods (e.g., 3 or 6 months), however, are often used, and in such cases reliable data on the seasonal variations of radon concentration are required to estimate the annual average value (e.g., Miles, 2001; Pinel et al., 1995).

The Italian National Survey on Indoor Natural Radiation (hereafter referred to as National Survey) was designed to obtain a representative estimate of the distribution of the annual average radon concentration in dwellings at the national level and, with a lower degree of precision, at the regional level as well. Moreover, the radon concentration was measured for two consecutive six-month periods (generally covering the spring-summer and the autumn-winter seasons), in order to obtain both the annual average value and the seasonal variations. The survey was designed, promoted and coordinated by the Istituto Superiore di Sanità, ISS (Italian National Institute of Health) and ENEA/DISP (later renamed ANPA and currently included in APAT, the Italian Agency for the Environment Protection and Technical Services), and it was carried out in 1989–1998 in collaboration with the 21 Regional Health Authorities and with the corresponding 21 Regional Reference Laboratories for the Control of Environmental Radioactivity (most of these Laboratories are now acting within ARPAs, the Regional Agencies for Environmental Protection). The results regarding national radon distribution derived from data of 19 Regions (all the Italian Regions except Sicilia and Calabria) were published elsewhere (Bochicchio et al., 1996).

In this paper, the final and complete results of national and regional distributions of both annual values and seasonal variations of radon concentration measurements, obtained in all the 21 Italian Regions, are reported and shortly discussed.

2. Material and methods

All materials and methods used in the National Survey, such as sampling design, experimental apparatus, measurement procedure, quality assurance program, and survey organization, have already been described elsewhere (Bochicchio et al., 1996), and are briefly summarized here, except for sample characteristics, which are discussed in detail in the following paragraph.

2.1. Sampling design

The sampling design was constrained by the need of using a representative sample of about 5000 dwellings for all the 21 Italian Regions (actually 20 Regions, one of which is formed by two administratively independent Provinces: Alto Adige and Trentino) and by the choice of adopting a door-to-door approach for contacting the families and distributing the detectors, in order to optimize the response. The number of 5000 sampled dwellings was chosen to guarantee an adequate knowledge of the radon distribution in Italian dwellings, and on the basis of the experience of previous similar surveys such as those in United Kingdom (about 2100 sampled dwellings), in Australia (3400), in Sweden (1400), in Finland (3100) and in the U.S.A. (5700) (Castrén, 1994; Langroo et al., 1991; Marcinowski et al., 1994; Swedjemark et al., 1993; Wrixon et al., 1988). However, the door-to-door approach prevented the use of a simple random sample, which would have spread over the whole territory, and involved an unfeasible large fraction of the about 8000 Italian towns. Therefore, a simple random sampling was used only for the 50 “large towns” (i.e., over 100,000 inhabitants), whereas “small towns” (i.e., less than 100,000 inhabitants) were cluster sampled, and 150 randomly selected. A two-stage stratified sampling scheme was used. The first stage included stratification and town sampling: each of the 21 Regions was subdivided in the two strata of large and small towns, giving a total of 39 strata because in three Regions there are no large towns. In the second stage, families were randomly sampled within each selected town, with the same sampling proportion of 1/4000 for all the strata. In five Regions (Valle d'Aosta, Trentino, Friuli-Venezia Giulia, Marche, Campania) a sample with a double number of dwellings and small towns was actually used in order to increase representativeness and precision of radon distribution estimate, so that the final total numbers of sampled dwellings and towns resulted slightly higher than the foreseen 5000 and 200, respectively.

The sampling design was taken into account when calculating regional and national average values. In particular, all the average values of annual radon concentration and of percentages of dwellings with radon concentration exceeding reference values were obtained from the corresponding data in each stratum by weighting by the population per stratum. Very similar results were obtained weighting by the number of dwellings per stratum, and therefore they will not be reported.

2.2. Radon concentration measurement devices

In all Regions, radon concentration was measured with ad hoc designed small passive devices (Azimi-Garakani et al., 1988). The holder, containing two SSNTDs exposed on the two sides of a cylinder (12 mm high, 24 mm diameter), was enclosed in a heat-sealed low density ($0.92\,g\,cm^{-3}$) $35\,\mu m$ thick polyethylene bag, which blocks radon decay products and thoron. Strippable cellulose nitrate film (KODAK LR115-II from Dosirad) was used as the main detector material, and the spark-counting technique was used for track counting (Cross and Tommasino, 1970). The radon measurement device was calibrated at the radon chamber of the National Radiological Protection Board (UK). Several intercomparison exercises, organized by APAT, were carried out during the survey in order to guarantee comparability of the measurement results from the different Regional Laboratories.

2.3. Seasonal corrections

In each dwelling, two measurement devices were placed close together in a regularly inhabited room, generally the bedroom, for two consecutive periods of about 6 months each, in order to obtain a total exposure of about 12 months. However, in 616 dwellings the results of only a single 6-month period were available, because of loss of the detectors or refusal by the dwellers. In such cases, the radon concentration measured in the single 6-month period was "corrected" so as to obtain an unbiased estimate of the annual average value. To this purpose, we used the geometric mean of the ratio of the radon concentrations measured in the two 6-month periods in other dwellings of the same town or of a nearby similar town.

2.4. Winter/summer ratios

The two 6-month exposure periods were generally chosen to cover the spring–summer (hereafter "summer") and autumn–winter (hereafter "winter") seasons, in order to estimate the presumable maximum seasonal variation of indoor radon concentration. However, for a small fraction of the sampled dwellings, the starting date was shifted so that the two 6-month periods were somewhat "mixed". For dwellings with validated results for both periods, the main parameters of the distribution of winter/summer ratio are calculated. In about 20% of cases, the actual measurement period lasted more (sometimes less) than 6 ± 1 months, but this affects only marginally the results of the analysis. Therefore, for the sake of brevity, only the results on the unrestricted data set are reported here.

3. Results and discussion

3.1. Coverage results

The door-to-door approach resulted in a reasonably low percentage of nonresponses, i.e. 24% on average, 18% in small towns, and 38% in large towns (Bochicchio et al., 1996). The numbers of measured dwellings and sampled towns are reported in Table 1. As described in the previous section, all the large towns were included in the sample, while only a small fraction of small towns were sampled.

3.2. National and regional average radon concentrations

The main results of measured annual radon concentrations for each Region are reported in Table 2, in particular the regional averages and the fractions of dwellings exceeding the reference values of $200\,Bq\,m^{-3}$ and $400\,Bq\,m^{-3}$ recommended by the European Commission for future and existing dwellings, respectively (European Commission (EC), 1990). When comparing the reported regional average values, uncertainties should be taken into account, which includes not only the reported standard errors, but also the standard error of the calibration factor, which was about 4% (Bochicchio et al., 1996), and the uncertainty connected with small town clustering, which can be considerable for those Regions where a low number of small towns was sampled. The regional averages—mapped in Fig. 1—are quite different, with the highest values found in Lazio, Lombardia, Friuli-Venezia Giulia, and Campania. These results have been generally confirmed by more detailed and sized surveys done later on in dwellings or kindergartens and primary schools of some Regions (Bochicchio et al., 1999; Gaidolfi et al., 1998; Giannardi et al., 2001; Giovani et al., 2001; Malisan and Padovani, 1994; Minach and Verdi, 2002). However, in three Regions (Sardegna, Alto Adige, Trentino), two

Table 1
Number of measured dwellings and sampled towns in the 21 Italian Regions

Region	Large town stratum[a]		Small town stratum[a]		All towns	
	No. of dwell.	No. of towns	No. of dwell.	No. of towns	No. of dwell.	No. of towns
Piemonte	110	2	311	23	421	25
Valle d'Aosta	—	—	24	3	24	3
Lombardia	198	4	622	30	820	34
Alto Adige	10	1	25	2	35	3
Trentino	17	1	62	10	79	11
Veneto	90	4	274	11	364	15
Friuli-Venezia Giulia	78	2	151	8	229	10
Liguria	88	2	98	4	186	6
Emilia-Romagna	153	9	216	6	369	15
Toscana	74	4	241	5	315	9
Umbria	24	2	49	2	73	4
Marche	19	1	220	11	239	12
Lazio	175	1	129	6	304	7
Abruzzo	11	1	92	6	103	7
Molise	—	—	28	3	28	3
Campania	81	3	705	25	786	28
Puglia	65	4	243	5	308	9
Basilicata	—	—	50	2	50	2
Calabria	31	3	136	8	167	11
Sicilia	109	4	228	5	337	9
Sardegna	25	2	99	7	124	9
All 21 Regions	1358	50	4003	182	5361	232

[a]The *large town* stratum comprises all towns with more than 100,000 inhabitants; the *small town* stratum consists of a random sample of towns with less than 100,000 inhabitants.

Table 2
Average annual radon concentration and fraction of dwellings exceeding the UE reference levels for the 21 Italian Regions

Region	Rn concentration ($Bq\,m^{-3}$)	Dwellings $> 200\,Bq\,m^{-3}$		Dwellings $> 400\,Bq\,m^{-3}$	
	AM ± SE	*N*	%	*N*	%
Piemonte	69 ± 3	9	2.1	3	0.7
Valle d'Aosta	44 ± 4	0	0.0	0	0.0
Lombardia	111 ± 3	70	8.4	18	2.2
Alto Adige	70 ± 8	2	5.7	0	0.0
Trentino	49 ± 4	1	1.3	0	0.0
Veneto	58 ± 2	7	1.9	1	0.3
Friuli-Venezia Giulia	99 ± 8	22	9.6	11	4.8
Liguria	38 ± 2	1	0.5	0	0.0
Emilia-Romagna	44 ± 1	3	0.8	0	0.0
Toscana	48 ± 2	4	1.2	0	0.0
Umbria	58 ± 5	1	1.4	0	0.0
Marche	29 ± 2	1	0.4	0	0.0
Lazio	119 ± 6	37	12.2	10	3.4
Abruzzo	60 ± 6	5	4.9	0	0.0
Molise	43 ± 6	0	0.0	0	0.0
Campania	95 ± 3	42	6.2	3	0.3
Puglia	52 ± 2	5	1.6	0	0.0
Basilicata	30 ± 2	0	0.0	0	0.0
Calabria	25 ± 2	1	0.6	0	0.0
Sicilia	35 ± 1	0	0.0	0	0.0
Sardegna	64 ± 4	3	2.4	0	0.0

AM = arithmetic mean; SE = standard error.

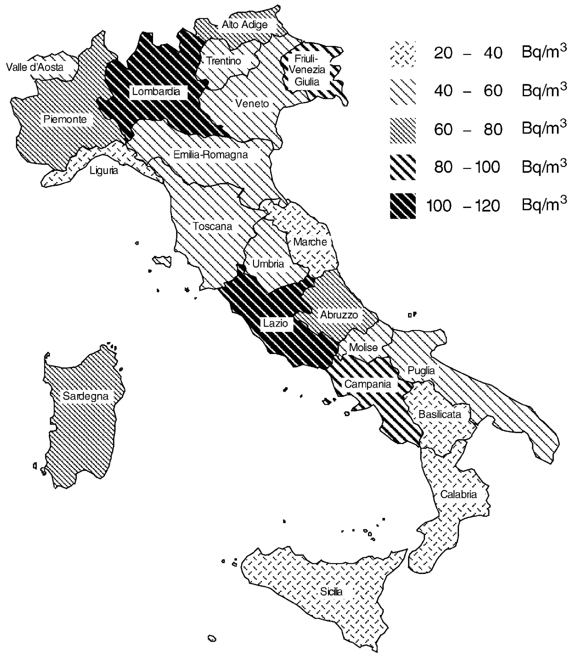

Fig. 1. Map of the average annual radon concentration levels in all the 21 Italian Regions as estimated from the National Survey. The actual regional average values for Trentino, Alto Adige, and Sardegna are actually significantly higher than the values mapped here (see text).

Table 3
Annual radon concentration distribution in Italian dwellings: summary results

	Large towns[a]	Small towns	All towns
No. of dwellings	1358	4003	5361
No. of towns	50	182	232
Max (Bq m^{-3})	843	1036	1036
AM (Bq m^{-3})	62	73	70
SE (Bq m^{-3})	1	2	1
GM (Bq m^{-3})	46	55	52
GSD	2.1	2.1	2.1
Dwellings > 150 Bq m^{-3}	6.5%	8.5%	7.9%
Dwellings > 200 Bq m^{-3}	3.3%	4.4%	4.1%
Dwellings > 400 Bq m^{-3}	0.5%	1.0%	0.9%
Dwellings > 600 Bq m^{-3}	0.2%	0.2%	0.2%

AM=arithmetic mean; SE=standard error; GM=geometric mean; GSD=geometric standard deviation.
[a]Over 100,000 inhabitants.

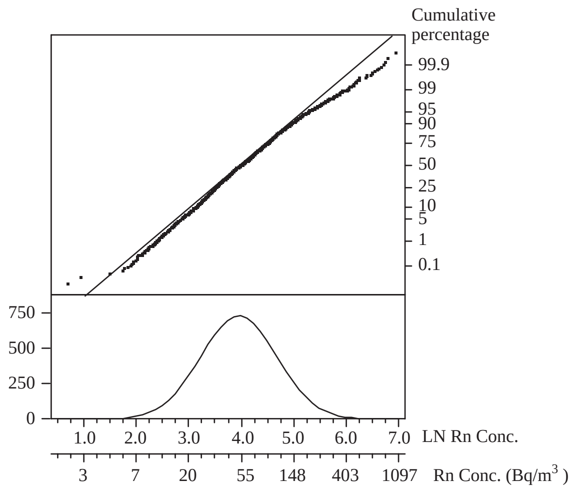

Fig. 2. Distribution of radon concentration in Italian dwellings under logarithmic transformation, and normal probability plot. This figure is based on the unadjusted log-normal model (see text).

small ones and an intermediate one for number of inhabitants, the radon concentration levels measured in these surveys were significantly higher than those obtained from the National Survey, where a much more limited number of dwellings and towns was sampled. Therefore, also these Regions (particularly Alto Adige) should be considered “high radon Regions”. Nevertheless, the underestimation of the radon concentration in these Regions does not considerably affect the national distribution (the national average would increase of about 2 Bq m^{-3}, only), because of the limited number of inhabitants compared with the entire Italian population.

3.3. Radon concentration distribution and log-normal approximation

Table 3 summarizes the national distribution of measured annual radon concentration values. The data are shown for the whole sample, for the stratum of towns with more than 100,000 inhabitants (large towns) and for the stratum of towns with less than 100,000 inhabitants (small towns). The radon concentration values in the small town stratum are on average higher than in the large town stratum, mainly because of a higher prevalence of low-rise buildings. In fact, the median value of the storey level of monitored rooms in small towns falls on the first floor, whereas in the large town stratum it falls on the second floor. The fractions of dwellings with measured annual radon concentration exceeding some reference levels (also called “action levels”) are also reported. The reference levels accounted for were: (i) 200 and 400 Bq m^{-3}, as recommended by the European Commission for future and existing buildings, respectively (EC, 1990); (ii) 150 Bq m^{-3}, as adopted by the U.S. Environmental Protection Agency, one of the lowest action levels; and (iii) 600 Bq m^{-3}, the highest in the range of reference levels recommended by the International Commission on Radiological Protection in its last publication on the matter (ICRP, 1993). At present, no national regulation on radon in dwellings is in force in Italy.

The distribution of annual radon concentration has approximately a log-normal shape (see Fig. 2). However, the

Table 4
Annual radon concentration at different storey levels: summary results

	Storey level							All
	B	G	1	2	3	4	⩾5	
All data								
AM ($Bq\,m^{-3}$)	108	89	73	63	56	55	51	71
SE ($Bq\,m^{-3}$)	14	3	2	2	2	3	2	1
Max ($Bq\,m^{-3}$)	336	828	892	1036	657	264	197	1036
$N0$	34	1058	2041	1080	473	236	306	5228
$N0/N0_{tot}$	1%	20%	39%	21%	9%	5%	6%	100%
Rn Conc. $> 150\,Bq\,m^{-3}$								
$N1$	7	142	177	55	13	8	3	405
$N1/N1_{tot}$	2%	35%	44%	14%	3%	2%	1%	100%
$N1/N0$	21%	13%	9%	5%	3%	3%	1%	7.7%
Rn Conc. $> 200\,Bq\,m^{-3}$								
$N2$	4	72	95	24	9	4	0	208
$N2/N2_{tot}$	2%	35%	46%	12%	4%	2%	0%	100%
$N2/N0$	12%	7%	5%	2%	2%	2%	0%	4.0%
Rn Conc. $> 400\,Bq\,m^{-3}$								
$N3$	0	22	19	3	2	0	0	46
$N3/N3_{tot}$	0%	48%	41%	7%	4%	0%	0%	100%
$N3/N0$	0%	2%	1%	0%	0%	0%	0%	0.9%

B = basement; G = ground floor; AM = arithmetic mean; SE = standard error.

number of dwellings with radon concentration higher than about 200 $Bq\,m^{-3}$ is significantly underestimated by the unadjusted log-normal model, i.e. using the geometric mean (GM) and geometric standard deviation (GSD) reported in Table 3, as already pointed out in a previous analysis on a sub sample of data (Bochicchio et al., 1992). Similar underestimates were already found in other surveys (e.g. Gunby et al., 1993; Castrén, 1994) and should be taken into account when log-normal parameters are used to estimate the fraction of dwellings exceeding any action level. A better agreement with the high tail of measured radon distribution can often be obtained if a low constant radon concentration value—representing the outdoor contribution to indoor concentration—is subtracted from each measured value before fitting distribution parameters (Gunby et al., 1993; Miles, 1994). This operation, which is equivalent to fitting data with a truncated log-normal model (also referred to as "three parameter" log-normal model), tends to increase the estimated GSD and, therefore, also the number of dwellings with high radon concentration estimated with the log-normal model. In Italy no representative assessment of the average outdoor concentration is available, therefore some different values were tried out. Using 10 $Bq\,m^{-3}$, i.e. the worldwide average estimated by UNSCEAR (2000), the GSD increases from 2.1 to 3.1 and the estimated fraction of dwellings exceeding 400 $Bq\,m^{-3}$ increases from 0.3% to 1.8%, to be compared with the observed 0.9%. A better agreement is obtained by using 7 $Bq\,m^{-3}$ as average outdoor concentration: GSD becomes 2.5 and the estimated fraction of dwellings exceeding 400 $Bq\,m^{-3}$ becomes 0.9%. A similar situation was found in the UK survey, where the subtraction of an outdoor value of 4 $Bq\,m^{-3}$ was found to resolve the log-normal underestimation (Gunby et al., 1993).

3.4. *The effect of storey level on the average radon concentration*

The dependence of the average radon concentration on the storey level of the room where the detectors were exposed can be analyzed in Table 4, that shows only the values measured in dwellings for which information on storey level was available, which excluded 133 dwellings. The unweighted distribution of the average radon concentration by storey level was reported for all the data and for the data exceeding the action levels discussed above. Owing to the low number of dwellings, however, the distribution was not reported for the 11 radon concentration values exceeding 600 $Bq\,m^{-3}$. The effect of soil as radon source can be clearly recognized: in fact, the fractions of high radon concentration values are significantly higher the lower the storey level. Moreover, the average radon concentration at ground level increases from 89 $Bq\,m^{-3}$ to 104 $Bq\,m^{-3}$ if there is no underlying storey, and decreases to 80 $Bq\,m^{-3}$ in the opposite case. However, some quite high radon concentrations have also been measured at levels higher than the first or the second floor, which might indicate a significant contribution from building

Table 5
Regional and national distributions of the "winter/summer ratio" of radon concentration: summary results

Region	(Winter Rn concentration)/(Summer Rn concentration) ratio							
	N	Min	Max	AM	Median	SD	GM	GSD
Piemonte	408	0.60	4.37	1.72	1.60	0.61	1.63	1.39
Valle d'Aosta	24	0.57	2.90	1.33	1.27	0.51	1.24	1.45
Lombardia	787	0.20	4.14	1.10	0.95	0.61	0.97	1.65
Alto Adige	35	0.88	5.71	2.74	2.58	1.01	2.58	1.44
Trentino	79	0.84	6.09	2.20	1.98	1.01	2.01	1.53
Veneto	105	0.16	2.22	1.02	1.01	0.39	0.93	1.61
Friuli-Venezia Giulia	226	0.52	4.99	1.60	1.45	0.70	1.47	1.49
Liguria	167	0.33	7.10	2.23	2.00	1.05	2.02	1.56
Emilia-Romagna	363	0.55	4.70	1.77	1.70	0.68	1.65	1.46
Toscana	308	0.29	5.11	1.87	1.75	0.74	1.73	1.47
Umbria	72	0.46	4.50	1.24	1.12	0.64	1.13	1.51
Marche	235	0.15	3.91	1.37	1.23	0.73	1.19	1.76
Lazio	214	0.28	2.86	0.89	0.82	0.43	0.81	1.56
Abruzzo	98	0.27	2.72	1.01	0.91	0.38	0.94	1.43
Molise	28	0.39	5.76	1.78	1.46	1.13	1.53	1.74
Campania	708	0.15	5.05	1.17	1.00	0.74	0.97	1.88
Puglia	299	0.38	4.77	1.55	1.43	0.70	1.41	1.54
Basilicata	50	0.61	3.18	1.29	1.21	0.40	1.24	1.32
Calabria	154	0.16	5.79	1.26	1.15	0.62	1.15	1.51
Sicilia	251	0.10	3.53	1.25	1.18	0.48	1.16	1.53
Sardegna	120	0.34	2.40	1.00	0.95	0.37	0.93	1.46
All 21 Regions	4742	0.10	7.10	1.41	1.26	0.76	1.23	1.71

AM = arithmetic mean, SD = standard deviation; GM = geometric mean; GSD = geometric standard deviation.

materials, especially in some Italian Regions, where materials with a high content of radium and thorium and high exhalation of radon, such as volcanic tuff in Central Italy, are widely used.

3.5. Seasonal variations of radon concentration

As regards the seasonal variations of radon concentration, the main parameters of the regional and national (unweighted) distributions of the "winter/summer ratio" (i.e., the ratio between the average radon concentrations measured in the autumn–winter 6-month period and in the spring–summer 6-month period) are reported in Table 5. Being radon concentration approximately distributed as a log-normal, the winter/summer ratio will also be distributed log-normally, and therefore the most useful parameters are the geometric mean and the geometric standard deviation. The data in Table 5 show a spread of the mean seasonal variations of the indoor radon concentration over Italy. As expected, radon concentration in winter was, on average, higher than in summer. For example this is true in several Northern Regions, such as Piemonte, Trentino, Alto Adige, Friuli-Venezia Giulia, where the air exchange during cold seasons is presumably quite low. However, similar results were also found in Regions of Central and Southern Italy. In some other Regions, such as Lazio, Abruzzo, Campania and Sardegna, the starting date of radon concentration measurements was shifted and/or spread over some months so that the two 6-month periods were somewhat "mixed", which lowered the mean values of the winter/summer ratio. However, in each Region there are dwellings where the measured radon concentration was higher in summer than in winter. Besides random variation, this can be attributed to specific living habits—i.e., dwellings kept closed for the summer vacation period, making the radon build up inside—or to particular microclimate in the air around the building, making the radon exhalation from soil higher in spring–summer than in autumn–winter.

Anyway, the distribution of the winter/summer ratio is considerably wide, on both a national and regional scale: in fact, the regional values of the GSD range from 1.32 to 1.88, with a median value of 1.51, and the corresponding national value is 1.71. This means that even in the Region with the lowest variability of the winter–summer ratio (Basilicata) there is about 5% probability of the winter/summer ratio being higher than GM $\times$ 2.6 or lower than GM/2.6. This variability should be considered when a seasonal correction factor is applied to correct, or convert, the result of 6-month measurements into annual average. This operation is quite reliable if applied to a large number of dwellings, because variability decreases as the square root of the number of measurements. Conversely, if an accurate and precise assessment of the annual average radon concentration in a single dwelling is required, a 12-month measurement is more appropriate.

4. Conclusions

In conclusion, the complete results of the Italian National Survey reported in this paper provide a reliable estimate of the national distribution of radon concentration in dwellings. This survey represents an adequate basis for planning more detailed regional surveys, some of which have already been carried out, although result uncertainty for low-populated Regions was necessarily higher than for high populated Regions. The log-normal model is a good approximation of the radon distribution, but it needs careful evaluation when used to estimate the fraction of dwellings with a high radon concentration. The role of both soil and building material as radon sources was highlighted by the analysis of the dependence of average radon concentration on storey level. Finally, the width of the distribution of the radon seasonal variation is considerable and has to be taken into account, at least in uncertainty evaluation, when a mean seasonal correction factor is applied to measurements shorter than 1 year in order to estimate the annual mean radon concentration.

Working group and acknowledgements

The Italian National Survey on Indoor Natural Radiation was designed, promoted and coordinated by G. Campos Venuti (ISS) and S. Piermattei (APAT). Other components of the national coordinating group: F. Bochicchio (ISS), who was also responsible for the data analysis; C. Nuccetelli and S. Risica (ISS); L. Tommasino and G. Torri (APAT), who were also responsible for the set-up of the radon measurement technique. The sampling scheme was designed in collaboration with R. Capocaccia, G. Farchi, and S. Mariotti (ISS). The following technicians contributed to the experimental and organizational activities: M. Cavaioli, M. Notaro, and M. Riccardi (APAT); F. Felici, A. Grisanti, G. Grisanti, and G. Moroni (ISS).

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