RESULTS OF THE NATIONAL SURVEY ON RADON INDOORS IN ALL THE 21 ITALIAN REGIONS

F. Bochicchio *, G.Campos Venuti *, S.Piermattei ^, G.Torri ^, C.Nuccetelli *, S.Risica *, L.Tommasino ^

* Physics Laboratory, ISS (Italian National Institute of Health)
Viale Regina Elena 299, I-00161 Roma, Italy
^ ANPA (National Agency for Environmental Protection),
Via V.Brancati 48, I-00144 Roma, Italy

The National Survey on Radon Indoors was designed to estimate the distribution of annual radon concentration in Italian dwellings, on the basis of a representative sample of about 5000 dwellings. It started in 1989 and ended in 1994, involving all Italian Regions except Sicilia and Calabria, due to organizational problems in these two regions of Southern Italy. After the official conclusion, two regional surveys were also carried out in Sicilia and Calabria, using the same experimental apparatus and protocols as in the other Regions. The final sample size was of 5631 dwellings distributed in 232 towns, i.e. all the 50 large towns (with more than 100,000 inhabitants) and a random sample of the smaller towns. The results in Sicilia and Calabria were characterized by quite low radon concentrations, thus moving the national radon distribution towards somewhat lower values. The updated national average, weighted by the population of each Region, of the annual radon concentration decreases from 75 Bq/m^3 to 70 Bq/m^3, the geometric mean decreases from 57 Bq/m^3 to 52 Bq/m^3, while the geometric standard deviation slightly increases from 2.0 to 2.1. The estimated national average values of the fraction of dwellings with radon concentration above the reference levels of 150 Bq/m^3, 200 Bq/m^3, 400 Bq/m^3, and 600 Bq/m^3 are 7.7%, 4.1% and 0.9%, and 0.2%, respectively. Regional averages range from about 25 Bq/m^3 to about 120 Bq/m^3. However, the uncertainty of regional values can be relevant in case of small Regions, where a low number of small towns were sampled, although such uncertainties do not affect significantly national values. In fact, while results in large Regions were generally confirmed by the more detailed regional surveys carried out in schools and/or in dwellings after the National Surveys, for three less populated Regions there are strong indications that the results from the National Survey were probably characterized by a relevant underestimation of regional radon concentration levels, although with a very limited effect (up to about 2 Bq/m^3) on the national average. In conclusion, the complete results of National Survey provided a reliable estimate of the radon national distribution in Italian dwellings, and represent the basis for more detailed regional surveys, some of which have already been carried out.

Key words: Indoor radon, survey

INTRODUCTION

After the several local and sparse surveys carried out in Italy in the 1980s, the Italian National Survey on Radon Indoors (hereafter referred to as National Survey) was designed to estimate the distribution of annual radon concentration in dwellings, on the basis of a representative sample both at national and at regional level, although with a lower precision in the latter case. The survey was designed, promoted and coordinated by ISS (Italian National Institute of Health) and ANPA (National Agency for the Environment Protection) and carried out in collaboration with the National Health System for dosemeter positioning and questionnaire filling, and with the CRR (Regional Laboratories for the Environmental Radioactivity Control) for radon measurements. It started in 1989 and ended officially in 1994, involving all the Italian Regions except Sicilia and Calabria, due to organizational problems in these two regions of Southern Italy. After the official conclusion, two surveys were also carried out in Sicilia and Calabria, using the same protocols for

dwelling sampling and the same detectors and instruments for radon measurements, as in the other Regions.

In this paper, the summary results of annual radon concentration measurements are reported and mapped for all the 21 Italian Regions. Moreover, the parameters of national distribution are updated to take into account the measurement results in the last two regional surveys.

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 will be detailed discussed in detail in the following paragraph.

The sampling design was constrained by the need of using a representative sample of about 5,000 dwellings for all the 21 Italian Regions (actually 20 Regions, one of which is formed by two administratively independent Provinces) and by the choice of adopting a door-to-door approach for contacting families and distributing dosemeters, in order to optimize response. The number of 5,000 sampled dwellings was chosen to guarantee an adequate knowledge of the radon distribution in Italian dwellings, also on the basis of the experience of previous similar surveys such as those in Britain (about 2,100 sampled dwellings), in Australia (3,400), in Sweden (1,400), in Finland (3,100) and in the U.S.A. (5,700) (Wrixon et al., 1988; Langroo et al., 1991; Swedjemark et al., 1993; Castrén, 1994; Marcinowski et al., 1994). However, the door-to-door approach prevented the use of a simple random sample, which would have been spread over the whole territory, involving an unfeasible large fraction of the about 8,000 Italian towns. Therefore, a simple random sampling was used only for the 50 “large towns” (having more than 100,000 inhabitants), whereas a cluster sampling was used for the “small towns”, involving 150 randomly selected ones. 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 Province, Friuli-Venezia Giulia, Marche, Campania) a sample with a double number of dwellings and small towns was actually used in order to increase representativeness, so that the final total numbers of sampled dwellings and towns resulted slightly higher than the foreseen 5,000 and 200, respectively.

The sample 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, reported in the following section, were obtained from the corresponding data in each stratum weighting by the population of each stratum. Very similar results were obtained weighting by the number of dwellings of each stratum, and therefore they will not be reported.

In all Regions, radon concentration measurements were performed using passive dosemeters, each containing two alpha track detectors (Azimi-Garakani et al, 1988). Strippable cellulose nitrate film (KODAK LR-115-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 dosemeter was calibrated

at the radon chamber of the National Radiological Protection Board. Several intercomparison exercises, organized by ANPA, were carried out during the survey in order to guarantee comparability of the measurement results of the different Regional Laboratories.

In each dwelling, two dosemeters were exposed close together in one inhabited room, generally the bedroom, for two consecutive periods of about six months each, in order to obtain a whole year of exposure. However, in 616 dwellings the results of a single six-month period were only available, due to loss of detectors or refusal from dwelling inhabitants. In such cases, the annual average value was obtained on the basis of the mean seasonal correction factor derived from results in the same town.

RESULTS AND DISCUSSION

The chosen door-to-door approach allowed to obtain a low percentage of nonresponses, which were 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. The main results of measured annual radon concentration in each Region are summarized in Table 2, in particular the regional average and the fraction of dwellings exceeding the reference values of 200 Bq/m^3 and 400 Bq/m^3 recommended by the European Commission for existing and future dwellings, respectively (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 is not negligible for those Regions where a low number of small towns was sampled. The regional averages – which are mapped in Figure 1 – are quite different, with the highest values found in the following four Regions: Lazio, Lombardia, Friuli-Venezia Giulia, and Campania. These results have been generally confirmed by the more detailed and sized surveys carried out, after the National Survey, in dwellings or kindergartens and primary schools of some Regions (Gaidolfi et al., 1998; Bochicchio et al., 1999). However, in three Regions 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, so that also these Regions should be considered “high radon Regions”. Nevertheless, these underestimates do not affect significantly the national distribution (the national average would increase up to about 2 Bq/m^3), due to the limited number of inhabitants living in those Regions, if compared with the total number of Italians.

The National Survey was not designed to find radon-prone areas, however some previously unknown area with high radon concentration have been identified. A more detailed description of the high radon areas in Italy is reported elsewhere (Bochicchio et al., 1999)

As regards the two most recent surveys in Calabria and Sicilia, their results are among the lowest in the range of the regional average radon concentration shown in tab.2, thus shifting the national distribution toward lower values. The results of the survey in Calabria, which was very well conducted, are probably somehow underestimated, due to an average total exposure period of about 14 months, which covered twice the months of July and August. On the contrary, the results of the survey in Sicilia, which underwent some organizational problems producing the exclusion of two

small towns from the final sample, are probably only slightly overestimated, due to an average total exposure period of about 14 months, which covered twice the months of October and November.

The summary results of the national distribution of annual radon concentration values are reported in Table 3. National values were obtained from regional values weighting by the number of inhabitants of each Region.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 fractions of measured dwellings with annual radon concentration exceeding a number of reference levels are also reported, including not only the levels recommended by the European Commission (EC, 1990), but also the level of 150 Bq/m^3 adopted by the U.S. Environmental Protection Agency, which is one of the lowest ones, and the level of 600 Bq/m^3, which is the highest value in the range of reference levels recommended by the International Commission on Radiological Protection in its last publication on the matter (ICRP, 1993). 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 floor level of monitored rooms is the first, whereas in the large town stratum it is the second.

The distribution of annual radon concentration generally follows the log-normal shape (see Figure 2). However, log-normal distribution calculated with the geometric mean and geometric standard values reported in Table 3 would result in a significant underestimation of high values, as already pointed out in a previous analysis on a sub sample of data (Bochicchio et al., 1992). Such underestimates were already found in other surveys (e.g. Gunby et al., 1993; Castrén, 1994). A better agreement with measurement results can be obtained when a low constant radon concentration value – representing the outdoor contribution to indoor concentration – is subtracted from each measured value (Gunby et al., 1993; Miles, 1994). This operation increases significantly the geometric standard deviation and, therefore, the estimated number of dwellings with high radon concentration.

The dependence of average radon concentration on floor level is reported in Table 4, where measurements in dwellings with information of storey levels are only considered, giving rise to the exclusion of 131 dwellings. The distribution with storey level was not reported for the 11 radon concentration values exceeding 600 Bq/m3 due to the low number of dwellings. The effect of soil as radon source can be clearly recognized: in fact, the fractions of high radon concentration values are significantly higher for lower storey levels. However, the trend is not extreme, and some quite high radon concentrations have been measured also in dwellings on floor levels higher than the first or the second one, pointing out a probable significant contribution of building materials.

WORKING GROUP AND ACKNOWLEDGEMENTS

The Italian National Survey on Radon Indoors was designed, promoted and coordinated by G.Campos Venuti (ISS) and S.Piermattei (ANPA). Other components of the national coordinating group: F.Bochicchio (ISS), C.Nuccetelli (ISS), S.Risica (ISS), L.Tommasino (ANPA), G.Torri (ANPA). The sampling scheme was designed in collaboration with R.Capocaccia, G.Farchi, and S.Mariotti (ISS).

The following people were responsible for the radon measurements in each Region: M.Magnoni (Piemonte); G.Agnesod (Val d'Aosta); G.Sgorbati and M.T.Cazzaniga (Lombardia); L.Minach and L.Verdi (Alto Adige); G.Frizzera and M.Bonomi (Trentino); F.Trotti and A.Mozzo (Veneto);

R.Padovani and M.R.Malisan (Friuli-Venezia Giulia); M.Roberti and Malgioglio (Liguria); L.Gaidolfi (Emilia); C.Giannardi (Toscana); R.Borio (Umbria); M.Lombardi (Marche); G.Cherubini (Lazio); S.D'Ostilio (Abruzzo); C.Cristofaro (Molise); R.Roca and G.Pugliese (Campania); V.Martucci (Puglia); A.Crispino (Basilicata); D.Colicchia and P.Cuzzocrea (Calabria); A.Sansone (Sicilia); M.Cappai (Sardegna).

The contribution of many people made this survey possible, including technicians for radon measurements, and public health officers for interviews and dosemeter positioning. A special thank is due to all the families who accepted to participate in the survey.

REFERENCES

[1] Azimi-Garakani D, Flores B, Piermattei S, Susanna AF, Seidel JL, Tommasino L, Torri G. Radon gas sampler for indoor and soil measurements and its applications. Radiat Prot Dosim 1988; 24: 267–272.

[2] Bochicchio F, Campos Venuti G, Mancioppi S, Piermattei S, Risica S, Tommasino L, Torri G. Natural radiation indoor exposure of Italian population. Proc. of the Int. Congress of the International Radiation Protection Association (IRPA 8), 17–22 May 1992, Montreal, Canada, 1992; Vol. II: 1561–1565.

[3] Bochicchio F, Campos Venuti G, Nuccetelli C, Piermattei S, Risica S, Tommasino L, Torri G. Results of the representative Italian national survey on radon indoors. Health Phys 1996; 71(5): 743–750.

[4] Bochicchio F, Bucci S, Bonomi M, Cherubini G, Giovani C, Magnoni M, Minach L, Sabatini P. Areas with high radon levels in Italy. Proceedings of Radon in the Living Environment Workshop, Athens, April 1999 (In this volume)

[5] Castrén O. Radon reduction potential of Finnish dwellings. Radiat Prot Dosim 1994; 56: 375–378.

[6] Cross WG, Tommasino L. A rapid reading technique for nuclear particle damage tracks in thin foils. Radiation Effects 1970; 5: 85–89.

[7] EC (European Commission). Commission Recommendation of 21-2-1990 on the protection of the public against indoor exposure to radon. (90/143/Euratom) Off J Eur Comm 1990; L80: 26–28.

[8] Gaidolfi L, Malisan MR, Bucci S, Cappai M, Bonomi M, Verdi L, Bochicchio F. Radon measurements in kindergartens and schools of six Italian regions. Radiat Prot Dosim 1998; 78(1): 73–76.

[9] ICRP (International Commission on Radiological Protection). Protection against radon-222 at home and at work. ICRP Publication 65. Annals of the ICRP 1993; 23(2): 1–45.

[10] Marcinowski F, Lucas RM, Yeager WM. National and regional distribution of airborne radon concentrations in U.S. homes. Health Phys 1994; 66: 699–706; 1994.

[11] Miles JCH. Mapping the proportion of the housing stock exceeding a radon reference level. Radiat Prot Dosim 1994; 56: 207–210.

[12] Swedjemark GA, Mellander H, Mjönes L. Radon levels in the 1988 Swedish housing stock. Proceedings of the 6th International Conference on Indoor Air Quality and Climate (INDOOR AIR '93), Helsinki, Finland, July 4-8, 1993, Vol.4, 491–496; 1993.

[13] Wrixon AD, Green BMR, Lomas PR, Miles JCH, Cliff KD, Francis EA, Driscoll CMH, James AC, O'Riordan MC. Natural radiation exposure in UK dwellings. NRPB–R190, Chilton, Didcot, Oxon; 1988.

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

Region	Large town strata		Small town strata		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 Province	10	1	25	2	35	3
Trentino Province	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

In each Region, large town stratum includes all towns with more than 100,000 inhabitants, whereas small town stratum includes a random sample of towns with less than 100,000 inhabitants.

Table 2: Summary results of annual radon concentration in the 21 Italian Regions.

Region	Rn Conc. (Bq/m^3) AM ± SE	Dwellings > 200 Bq/m^3 N	%	Dwellings > 400 Bq/m^3 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 Province	70 ± 8	2	5.7 %	0	0.0 %
Trentino Province	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

Table 3: Summary results of annual radon concentration in Italian dwellings.

	All towns	Large towns	Small towns
No. of dwellings	5361	1358	4003
No. of towns	232	50	182
Max (Bq/m^3)	1036	843	1036
Arithmetic Mean (Bq/m^3)	70	62	73
Standard Error (Bq/m^3)	1	1	2
Geometric Mean (Bq/m^3)	52	46	55
Geometric Standard Deviation	2.1	2.1	2.1
Dwellings > 150 Bq/m^3	7.9 %	6.5 %	8.5 %
Dwellings > 200 Bq/m^3	4.1 %	3.3 %	4.4 %
Dwellings > 400 Bq/m^3	0.9 %	0.5 %	1.0 %
Dwellings > 600 Bq/m^3	0.2 %	0.2 %	0.2 %

Large towns have more than 100,000 inhabitants.

Table 4: Summary results of radon concentration at different storey levels.

	Storey level							
	B	G	1	2	3	4	≥ 5	tot
All data								
AM (Bq/m^3)	108	89	73	63	56	55	51	70
Max (Bq/m^3)	336	828	892	1036	657	264	197	1036
N0	34	1058	2041	1080	473	236	306	5228
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/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/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/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

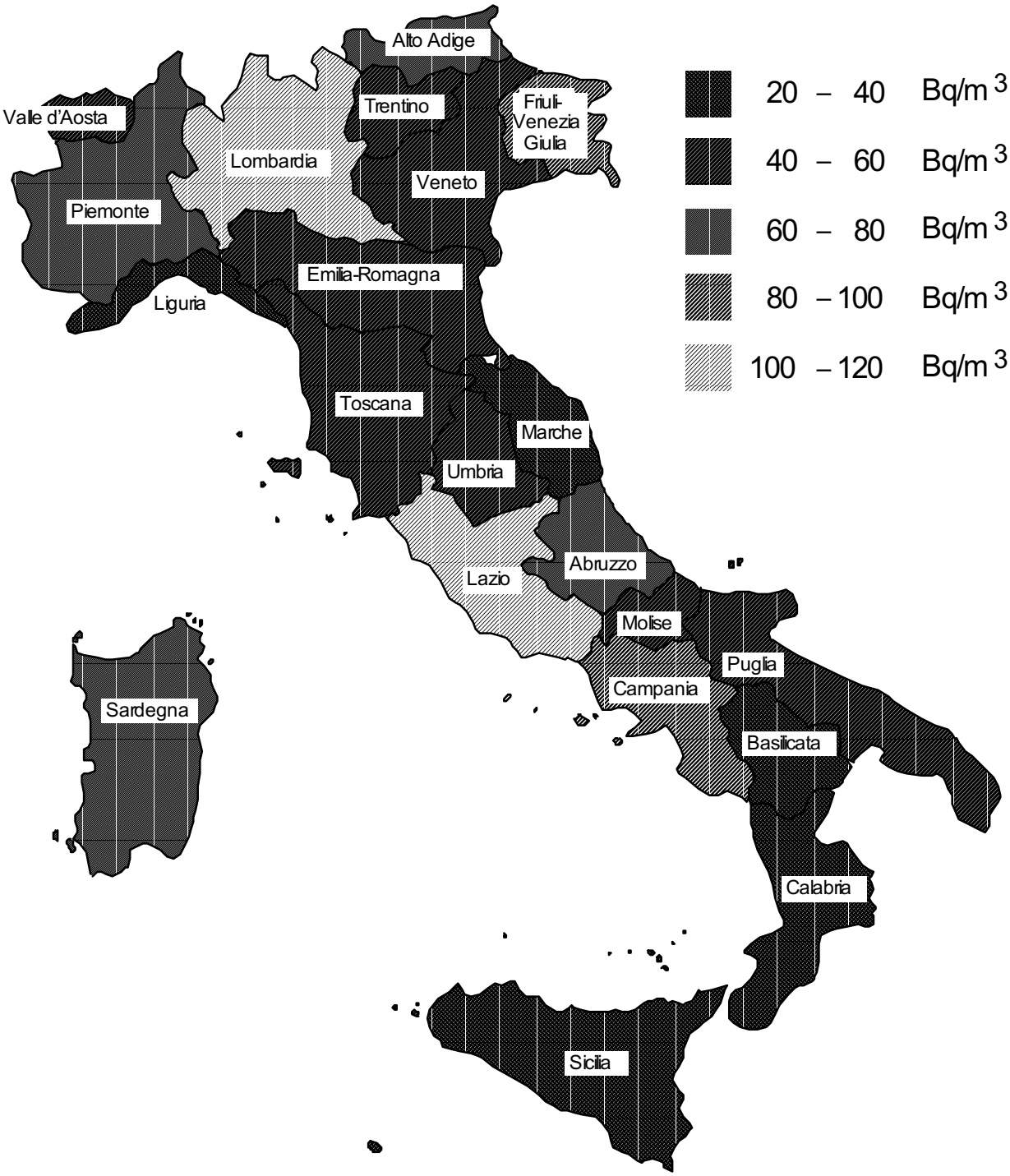

Figure 1: Map of average annual radon concentration in all the 21 Italian Regions as estimated from the National Survey. The actual regional average values of Trentino Province, Alto Adige Province, and Sardegna are significantly higher than the mapped values (see text).

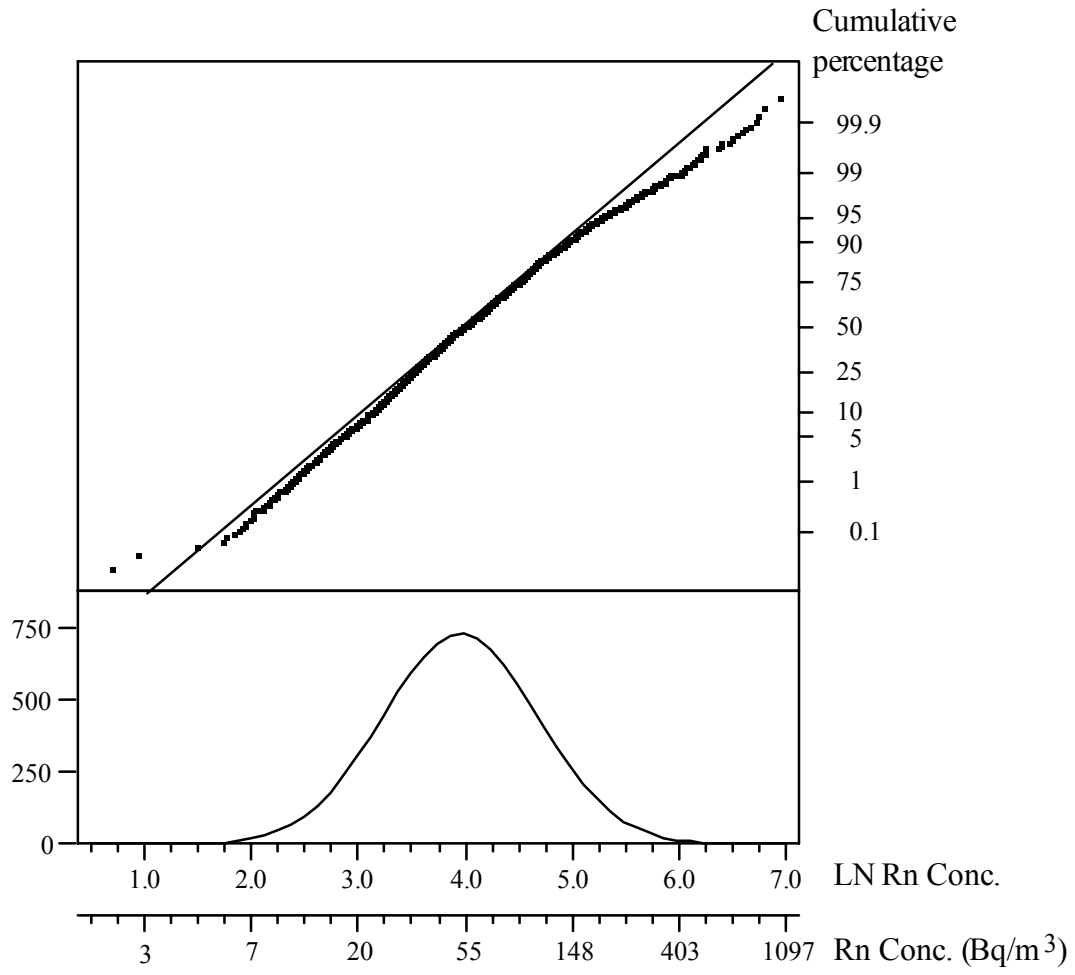

Figure 2: Distribution of radon concentration in Italian dwellings under logarithmic transformation, and normal probability plot.