TA6 - Radiation Protection of the Public and the Environment

Radon gas monitoring survey for the determination of Radon Prone Areas in Lombardia

S.Arrigoni[2], D.de Bartolo[1], A.Alberici[1], P.Cazzaniga[2], A.Cugini[2], G.Gallinari[2], R.Gallini[1], T.Maggioni[1], A. Mondini[1], F.Olivieri[2], M.Romanelli[2], E. Zini[1]

[1]*A.R.P.A. della Lombardia, Sede Centrale, Milano, Italy*

[2]*A.R.P.A. della Lombardia,Dipartimento di Bergamo, Bergamo, Italy*

ABSTRACT

Region Lombardia has carried out a radon gas monitoring survey on its territory to localize radon prone areas as by law 241/00 enacted.
To plan the survey, the Lombardia's territory has been divided into two different types according to the morphology as well as the presence of a substratum of rock. The area with hills and mountains has been investigated with more attention compared to the plain because we can assume higher variability in radon concentration distribution due to the geological and morphological characteristics. The territory subdivision was based on the standard grid.. of the technical regional cartography (8x5 km).
To perform radon indoor concentration measurements about 3600 measuring points were selected. They are located at the ground floor of buildings with the characteristics to ensure the tests are representative and comparable. It has also been taken taken into account evaluations done with previous surveys in accordance with the defined specification of the sites.
The measurements were carried out using CR 39 trace detector technique. The detectors were contained in closed plastic canisters and they were positioned in situ for one year and measured each semester.
The detectors were chemically treated and the traces counted using the automated optical system installed at the Radiometric Laboratory of the ARPA Department in Bergamo.
The instrument accuracy and precision were evaluated using data obtained with different methods: using detectors exposed to radon known concentrations, participating to an international intercomparison as well as exposing the detector in a national calibration centre.
Due to the large amount of detectors involved, a particular attention was taken for the detector homogeneity response and for the optimization of the analysis parameters. For further investigating the reliability of the measurements, two detectors were used in parallel in 10% of the tests.
The results show higher values in the areas of Bergamo, Brescia, Lecco, Sondrio and Varese.
For the 84.6 % of all the measurement points, the concentrations measured were lower then 200 Bq/m^3, and 4.3 % were higher then 400 Bq/m^3, with 0.6 % higher than 800 Bq/m^3 .
Spatial variation of indoor Rn concentrations is modeled. Geostatistical analysis and GIS techniques were used to localize radon prone areas.

INTRODUCTION

In Italy many indoor radon concentration measurements have been performed in previous surveys in the last 15 years by ASL (Local Health Agencies), ARPA (Regional Agency for Environmental Protection) and Universities.
A national survey was carried out around 1990, measuring almost 5000 dwellings in Italy, 818 in Lombardia.
The average annual concentration value in Italy was 70 Bq/m^3; in Lombardia it was 116 Bq/m^3 and the highest concentrations were found in the north-east of Milan area, as well as in Bergamo and Sondrio areas.
Italian laws don't consider radon in dwellings at all: for this reason we consider as reference the 90/143/Euratom recommendation, which suggests 400 Bq/m^3 as limit value for existing dwellings and 200 Bq/m^3 for new buildings

Fig 1 Location of Lombardia in Italy

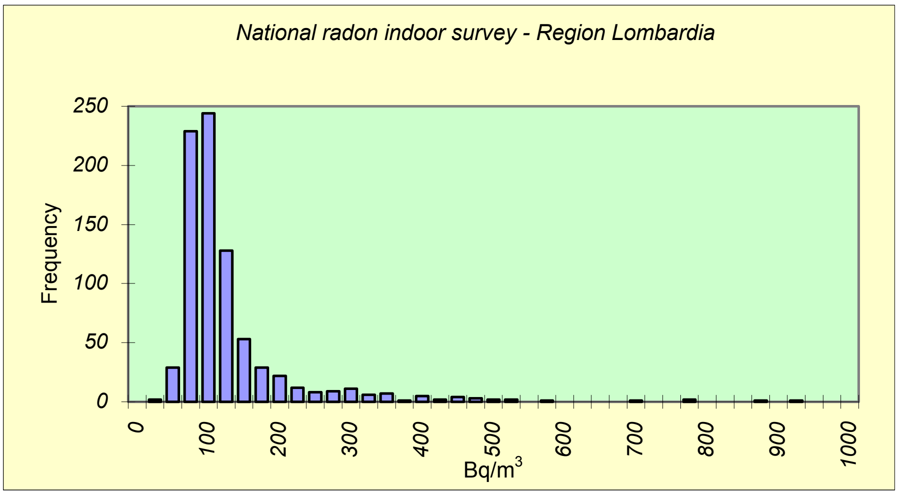

Fig. 2 National radon survey was performed between 1989 and 1991; in Lombardia more than 800 dwellings located in 34 small villages or towns, and four cities with more than 100.000 inhabitants (Milano, Brescia, Monza and Bergamo) were involved. The average annual radon concentration in Lombardia was found to be 116 Bq/m^3, higher then the national average.

Mapping survey for the determination of radon prone areas in Lombardia (2003-2005)

Italian law (art. 10-ter, comma 2, D.L.vo 241/00) enacted that each Region should define radon prone areas.
The Region Lombardia deliberated in 2003 to start a mapping survey of its territory.
The analysis of numerous previously performed measurements in Lombardia has shown they were extremely heterogeneous by technique and by characteristics of the rooms investigated.
As a consequence, in order to have representative and comparable concentration measurements to define a radon prone areas map, it has been decided to choose ground floor rooms, dwellings or public offices, built or renovated after 1970, with cellar or underfloor air space, having a volume smaller than 300 m^3.
Among the 4500 previously measured points, 350 were conform to the characteristics of the monitoring plan.
The chosen characteristics should restrict the variability due to the parameters that influence radon indoor concentrations.
For each point, all the information related to the characteristics of the rooms and of the buildings have been collected (number of the windows, building materials, etc..).
To plan the survey, the Lombardia's territory was divided into two different types according to the morphology as well as the presence of a rock substratum. The area with hills and mountains has been investigated with more attention compared to the plain because we can assume higher variability in radon concentration distribution due to the geological and morphological characteristics. The territory subdivision was based on the standard grid of the technical regional cartography:

- *Mesh 8 km x 5 km, (or smaller that is to say 2.5 km x 8 km or 4 km x 5 km where it was necessary to better investigate) for the prealpine/alpine area and Oltrepò Pavese (substratum of rock less than 50 m under the ground soil);*
- *Mesh 16 km x 10 km for the plain (with substratum under the alluvial stratum, more than 50 m under the ground soil).*

In each mesh 5 up to 10 measurement points were chosen, nearly 3600 points in the whole Lombardia, placed in 541 towns or small villages (1/3 of the total amount).
The location of the measurements is shown in fig. 3.
The measurements were performed for one year starting from October 2003, using passive detectors for two six months consecutive periods.

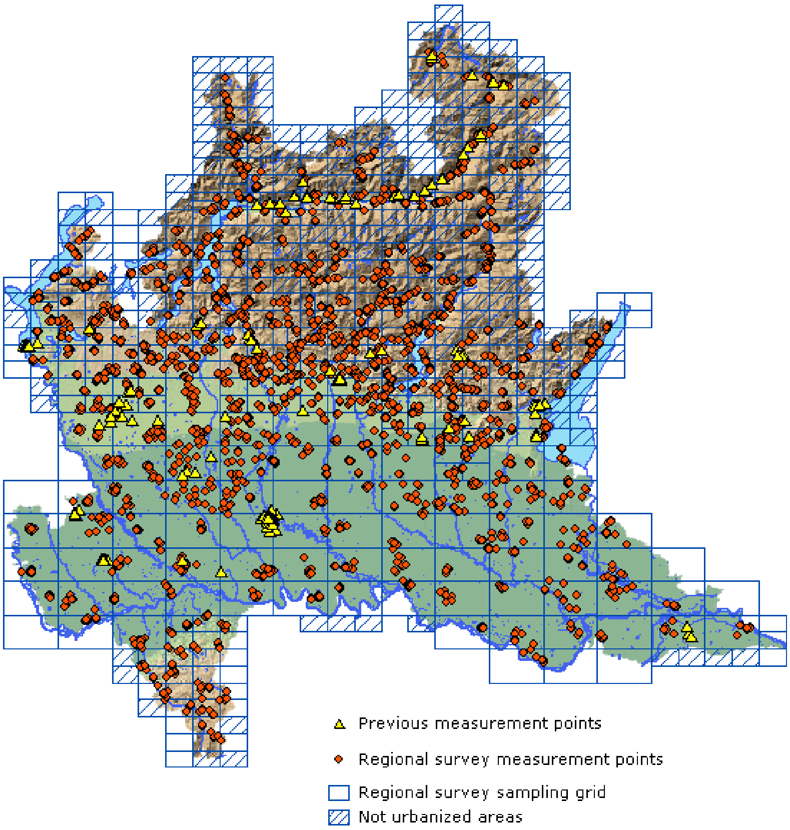

Fig. 3: Monitoring survey for the determination of radon prone areas in Lombardia (2003-2005)
- measurements location
5 up to 10 measurement points were found for each mesh with urbanized centers. Previous measurements with homogeneous characteristics were also considered.

Measurement technique

A long term technique was used to evaluate the average annual radon indoor concentration. Trace detectors (CR-39) were used; they are plastic square chips (poliallil-diglicol-carbonate, PADC) 10x10x1mm, sensitive only to alpha radiations, placed under the cover of closed plastic cylindrical canister, a diffusion chamber of 35 mm diameter x 55 mm height .
The detectors are vacuum-packed until the beginning of the exposure.
The screw plug of the canisters must not be opened or unscrewed during the exposure time.
The radon gas enters the diffusion chamber through the fissure between the plug and the canister and damage is induced to the chemical bonds of the material by the alpha particles produced in the decay of radon and radon progeny. Traces are created on the surface of CR-39.
At the end of the exposure the detectors are sealed up until the chemical treatment.

The traces number is proportional to the exposure time and to the gas concentration in the environment and, after a chemical treatment, can be evaluated by means of optical methods.
The chemical attack develops the traces produced by radiations on CR-39, to make them visible and quantifiable. The CR-39 must be removed by the canisters and placed into 12 places in plastic slits. The slits are then immersed for 4 hours in a thermostatic bath with NaOH solution at 90°C.
Each slit is inserted in the Radosys reading system, which consists essentially of an optical microscope with automatic positioning. The management software recognizes the identification code of each dosimeter, finds and counts the number of traces which have fixed characteristics in shape and color. The result of the reading is the traces density.
The system has been calibrated by the exposure of at least 10 detectors to 3 different known values (the average concentration by the exposure period) and by chemically attack of the detectors and by reading as described before.
The calibration factor (fc) must be calculated for each detectors lot. Because the utilized detectors were produced more than six months before, it was necessary to repeat the calibration to correct for the sensitivity, which decreases with time.
The system has been calibrated in the range of 400 to 4000 $kBq*h/m^3$ (corresponding to a 6 months exposure at 800 Bq/m^3 concentration).
The system has been checked evaluating the percentage difference between the reference value and the standard deviation. This has been performed every 1000 measurements in order to check the optical system. The automatic reading system gives the traces density for each scanned detector.
Starting from that value and the exposure period, the average radon concentration in that point has been evaluated:

RaC = activity concentration of radon gas (Bq/m^3) = E/t
where:
E = Exposure ($kBq*h/m^3$)
t = detector exposure time (h)

$E = (D - Df)*fc$
where
D = measured trace density ($trace/mm^2$)
Df = average background trace density for detectors of the same lot ($traces/mm^2$)
fc = calibration factor for detectors of the same lot ($(kBq*h/m^3)/traces/mm^2$)

Repeatability tests were performed (300 e 3000 $kBq*h/m^3$), for the two reading modes
("slow", that analyses the whole detector's area, and "fast", that analyses some portions of the detector's area) :
.- consecutive readings of the same detector: average standard deviation of 2% for the reading in "slow" and 6% in "fast" mode.
- readings of different detectors of the same lot, at the same exposure conditions and value, same chemical attack and all measured the same day: average standard deviation 6% for "slow", 8% for "fast", 20% for the readings of background exposed detectors.
These tests have been performed some time later and the values were comparable (one standard deviation).

*The system is linear in net traces density (D-Df) for exposures lower than 4000 kBq*h/m³.*
*The detection limit is 10 Bq/m³ for a six months exposure, at about 40 kBq*h/m³.*
The system producer took part in the 2003 international intercomparison performed by NRPB, and resulted class A (error < 10%).

RESULTS

The results of the radon gas monitoring survey are shown in the table below.
The measurement points were about 3600 in total, spread in the different areas as the table 1 shows. 350 were the points previously measured and in keeping with the characteristics of the monitoring survey.
The preliminary results confirm the importance of the problem of radon in Lombardia's territory.
4.3 % of all the measurement points, placed in rooms on the ground floor, had average annual concentration values higher than 400 Bq/m³ and the higher values were in Bergamo, Brescia, Lecco, Sondrio and Varese areas.
In Lodi and Cremona areas the measured concentrations were all lower than 200 Bq/m³.
In Fig 4 the percentage distribution of the values is shown.
.

Area	% values lower than 200 Bq/m³	% values in the range between 200 - 400 Bq/m³	% values in the range between 400 - 800 Bq/m³	% values higher than 800 Bq/m³	Number of measurements
Bergamo	75.1	15.8	6.6	1.6	594
Brescia	82.8	11.7	4.3	0.5	809
Como	87.9	10.6	1.1	0.0	264
Cremona	100.0	0.0	0.0	0.0	150
Lecco	82.2	11.5	3.8	1.4	287
Lodi	100.0	0.0	0.0	0.0	87
Milano	93.3	6.3	0.4	0.0	255
Mantova	98.7	1.3	0.0	0.0	150
Pavia	98.2	1.8	0.0	0.0	340
Sondrio	70.6	20.7	7.3	1.4	425
Varese	79.2	14.5	5.2	0.3	289
Lombardia	84.5	11.1	3.7	0.6	3650

Table 1: results of the regional survey for the determination of the radon prone areas: percentage concentration values distribution of the annual average, distributed in the different areas

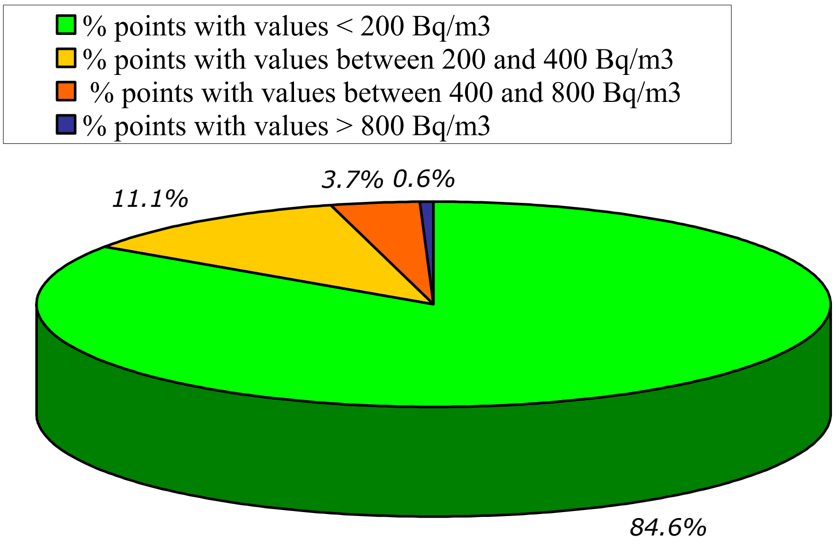

Fig. 4: percentage distribution of the average annual radon concentrations in the regional survey monitoring for the determination of radon prone areas in Lombardia.

GEOSTATISTICAL ANALYSIS

Spatial distribution of environmental measurements, as the case of indoor radon measurements, includes both deterministic and random contribution. The deterministic variability is a trend generally related to known factors; random variability has not direct explanation, and is the result of known factors together with unknown factors which have influence on very different space-time scales.
A geostatistical approach is generally requested to identify a representative model for this interaction without investigate the causes.
In this work, a model has been created with the Kriging technique on the basis of the semivariogram analysis.
The distribution is lognormalized The construction of a representative model for the semivariogram needs the choice of many parameters which identify the scale of the geostatistical field to be represented.
A non-exact model has been chosen to give prominence to mesoscale interactions, with a lagsize almost 0.6 (which shows a great variability for the values on microscale, as already found by the Voronoi map) partially smoothed by a 20% uncertainty on the measurements.
The spherical model best fit the numerical semi-variogram. The cross validation predicts errors of
Average =-0.71
Standard average= -0.00032
RMS Standard =0.92
As usual the Kriging prediction underevaluates the outlets. The Fig .5 shows the prevision and probability of overcoming the threshold of 400 Bq/m^3

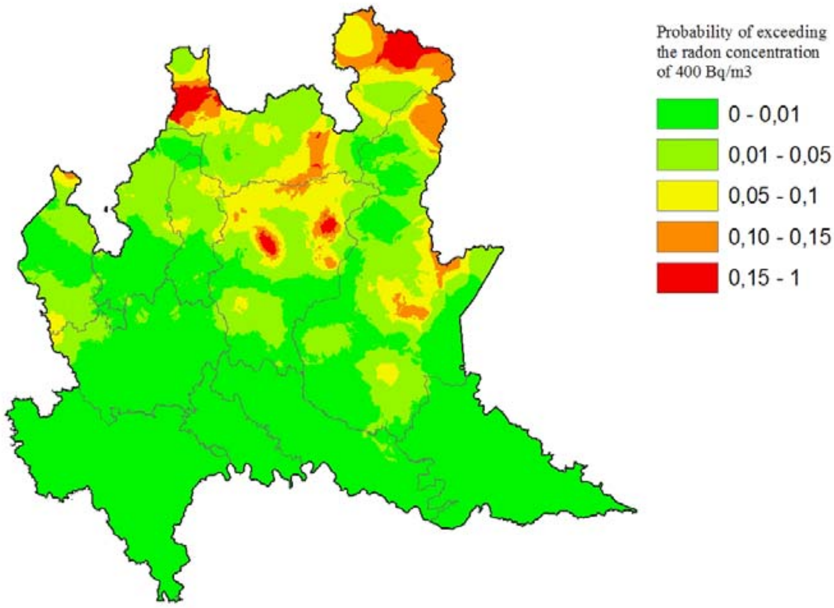

Fig. 5 Lombardia probability map of exceeding the radon concentration value of 400 Bq/m^3 , obtained by kriging technique starting from the radon indoor measurements of the regional survey.

As shown in the map, the higher radon concentration values can be found in the northern part of the region, in correspondence to some of the mountain areas where also the previous measurements results were high.

CONCLUSIONS

The first results of the measurements performed in the regional radon survey in Lombardia confirm the strict connection between the presence of radon and the geological characteristics of the territory, showing higher indoor radon concentrations in Bergamo, Brescia, Lecco, Sondrio and Varese areas.
In the 84.6 % of all the measurement points, located in rooms on the ground floor, the concentrations measured were lower then 200 Bq/m^3, and 4.3 % were higher then 400 Bq/m^3, with 0.6 % higher than 800 Bq/m^3 .
Statistical and geostatistical analysis are carried out to define the radon prone areas.
In the meanwhile, epidemiological consideration and regional actions to reduce the radon indoor exposure are arranged.

BIBLIOGRAPHY

1. *Bochicchio, F. et al. – Results of the Representative Italian National Survey on Radon Indoors – Health Physics 17(5), 741-748 (1996)*
2. *90/143/EURATOM 21/02/1990*
3. *Decreto Legislativo 26/05/00 n. 241: Attuazione della direttiva 96/29/EURATOM in materia di protezione sanitaria della popolazione e dei lavoratori contro i rischi derivanti dalle radiazioni ionizzanti.*

4. *ICRP. Protection against Radon-222 at Home and at Work. Ann. ICRP 23(2), Publication 65 (1993)*
5. *Akerblom G. e Mellander H.,1997."Geology and Radon", Radon measurements by etched track detectors. 21-49, World Scientific.*
6. *NRC, 1988, National Research Council, Committee on the Biological Effects of Ionizing Radiation, "Health Risk of Radon and other deposited Alpha Emitters: BEIR". National Academy Press, Washington, DC.*
7. *Pellegrino C., Tagni M., Dell'Oca M., Fascendini A., luglio 2000. Studio di un modello previsionale per la valutazione delle concentrazioni di Radon indoor a partire dalle caratteristiche geologiche del sito. Arpa Lombardia, Dipartimento di Sondrio*
8. *Instruction Guide "Radosys 2000"*
9. *Ministero Salute, Piano Nazionale Radon, 2002, Draft*
10. *Mostacci D.: Strumentazione e modalità di misura nel settore della radioattività naturale. Notiziario ANPEQ, n.ro 61-62: 48-53, 2002.*
11. *B. Dörschel , D. Hermsdorf , J. Sichelschmidt , S.Starke ,Investigation of free radicals induced by light ions in CR-39 using ESR*
12. *ANPA, "Il sistema informativo territoriale per la valutazione del potenziale di esalazione di radon dal suolo", Serie Stato dell'Ambiente 9, 2000.*