A SURVEY TO MAP AREAS WITH ELEVATED INDOOR RADON LEVELS IN VENETO


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CRR, the Regional Center for Radioactivity, is monitoring Veneto, a region in the north-east of Italy, to trace a map of areas with elevated indoor radon levels. This survey is based on analysis of territorial distribution of radon concentration in dwellings. Maps of potential risk are searched in the upper part of the region based on the indication of a previous survey. Percentage of dwellings exceeding reference levels are estimated on the base of log-normal data distribution. Normalizations to ground floor or average housing type are produced. Preliminary results indicate the existence of three areas with elevated indoor values. Radon levels often seem to be well correlated with geology.

Key words: Radon, mapping, Veneto, dwellings, grid rectangles, passive dosimeters

INTRODUCTION

Since radon has been recognised to be, on average, the predominant contributor to natural radiation exposure of population, different international organisations have undertaken control programs on the territories in order to identify radon affected areas for prevention policies.

At the end of the 1980s a national campaign was conducted in Italy involving regional authorities; the survey was aimed at assessing the mean radon concentration in dwellings both on national and regional scale and for this purpose random samples of dwellings were selected for measurements (Trotti et al., 1994).

CRR, supported by Veneto Region’s Administration, is now developing an accurate analysis of the venetian areas supposed to have high levels.

The aim of the project is to trace a map that clearly defines the territorial distribution of radon concentration to use as tool for control, prevention and remedy. The map should come out from radon measurements in dwellings, accordingly to other international approaches (Piller et al., 1997) (Miles et al., 1991).

This article intends to be an updating of the previous preliminary results (Trotti et al., 1998).

MATERIALS AND METHODS

Survey criteria

To trace a map of the principle areas of potential risk in Veneto, the whole territory has been analysed with the exception of the alluvial plane composed of clay and silt drifts, focusing on the upper part of the region where the previous campaign gave indication of probable high radon levels.

The area has been divided in grid rectangles (5.6x6.5 Km$^2$) coinciding with CTR (Region Technical Chart) 1:10000 sections. For each one at least five dwellings are monitored pointing out the annual
concentration of radon; the results can be normalized to ground floor or to typical house condition (see section 2.3.1).

At each rectangle are attributed the empirical geometric mean and the percentage of dwellings exceeding reference levels, based on log-normal data distribution assumption.

Table 1 shows the current state of survey in the beginning of 1999 in terms of involved and predicted monitoring units and dwellings.

Figure 1 also reports information on it.

**Operative procedure**

Assessments consist in annual exposures, based on two six-monthly samplings, carried out with passive permeation dosimeters using CR-39 track detectors.

The detectors undergo chemical etching (NaOH 6.25 N-15h-72°C) to make tracks visible and then are read by a locally made automatic image analyser (Trotti et al., 1997). Dosimeters calibrations are made in NRPB (UK) radon chambers.

Technical management and organisational coordination are assigned to CRR; local ARPAV (Environmental Protection Agency of Veneto) laboratories and Town Councils select dwellings, fill out a questionnaire with information about houses and their occupiers, in order to set correlations with radon levels, and provide distribution and collection of dosimeters.

**Methodology**

**Data normalization**

On the base of the results derived from the statistically significant regional survey previously mentioned (see section 1), a subset has been selected excluding house data strongly influenced by local geology or distorting the whole sample. For houses with same monitored room floor, the average concentration has been computed: a decreasing trend for radon levels resulted with increasing floor; not significant differences appeared to be for second and higher floors.

Table 2 shows monitored room’s floor average concentration together with the ratios of its normalisation to ground floor concentration.

Assuming that radon concentrations at defined floors do not depend on the house type, measured concentration values can be normalized to ground floor using data in Table 2.

Normalising values to ground floor permits to trace a map that better represents the prominent radon source (soil) based on the evidence that measured levels in Veneto are dependent essentially on geology, other contribution as building materials or outdoor air being less important. Excluding the house floor dependence in the analysis of the previous survey, better agreement with log-normal distribution comes out, giving, consequently, less data dispersion.

Referring to the regional house stock (distribution of house type with respect to floor) in Figure 2, obtained from Census of Italian population (ISTAT, 1981), the regional weighted mean (RM) can be obtained:
\[ RM = \frac{\sum_i (R_{n,i}N_{h,i})}{\sum_i N_{h,i}} \]

(1)

where \( i \) indicates floor based house type (ground floor, first floor, first+ground floor, first floor+second floor, second floor, higher than first floor, higher than second floor);

\( R_{n,i} \) is the average radon concentration for \( i^{th} \) house type, from Table 2; where multi-storey houses are considered, arithmetic mean of single floors are used;

\( N_{h,i} \) is the number of houses of \( i^{th} \) house type in Veneto (Figure 2).

Ground floor estimate can be converted in regional housing stock corrected value multiplying by:

\[ \frac{RM}{R_{n,g}} = 0.842 \]

(2)

where \( R_{n,g} \) is the average concentration for ground floor houses (Table 2).

Adapting equations (1) (2) to specific housing stocks, local house type estimates can be performed. 120 monitored dwellings have only the first semester datum, the second semester still being monitored. To make annual projections of these single semester cases, a factor evaluated from the seasonal variation has been used: the ratio of average concentration data of 313 dwellings monitored over two consecutive six months periods. Its value is:

\[ \frac{\bar{W}}{\bar{S}} = 1.16 \pm 0.43. \]

(3)

where \( \bar{W} \) is the average concentration of radon measured over the winter semester and \( \bar{S} \) over the summer semester.

**Frequency distribution of radon level**

Assuming log-normal frequency distribution of radon levels in each grid rectangle, single geometric mean (GM) and geometric standard deviation (GSD) have been calculated after data normalisation to ground floor. GM comes from specific rectangle data while GSD is evaluated as follows. Using all data actually available from this survey and the previous one, in grid rectangles with acceptable statistics, it has been observed that the relative geometric standard deviations of concentrations normalised to ground floor are fairly constant.

The reference value determined from the average on seven rectangles with more than twelve monitored dwellings in each is:

\[ \frac{GSD}{GM} = 0.0277 \pm 0.0052. \]

(4)
To every rectangle is thus assigned the absolute GSD value, obtained from the value of equation (4) through the multiplication by the rectangle specific GM value.

Finally, to trace the map of high radon levels areas, the percentage of houses in each grid rectangle exceeding the reference level (RL) is calculated from the normal distribution probability associated to the standardised deviate:

$$ Z = \frac{\ln(RL) - \ln(GM)}{\ln(GSD)} $$

(5)

where RL is the representative reference value in dwellings, estimated to be 600Bq/m$^3$ (ten times the regional average, that is 59 Bq/m$^3$ in Veneto, according to ICRP,1993). This value is used just to test the model, waiting for the official Italian reference level.

Substituting, in equation (4), GM with the value corrected by means of equation (2), the percentages of dwellings exceeding the reference level, with regard to the actual regional house types, can be obtained.

RESULTS

The map representing the percentage of homes exceeding the reference level of 600 Bq/m$^3$ in each grid rectangle, for the current state of the survey, has been traced in Figure 2.

Data are corrected with reference to the regional housing stock.

The preliminary results indicate elevated radon levels in upper Belluno province, in Asiago highland and Euganean Hills; lower values appear in southern Belluno province and in the piedmont bend and Garda lake areas of Verona province.

Some correlations with local geology exist: in particular rhyolite, acid volcanic rock is diffused in Euganean Hills area and typical limestone subjected to karst phenomena (Scaglia rossa) is present in Asiago highland.

Low Verona province values can be interpreted in terms of presence of moreinal and alluvial drifts.

An uncertain correlation is found in Cadore and Agordino, areas of dolomites and calcar rocks, (not strongly affected by karst phenomena), where elevated values have been recorded; a first hypothesis is that geology itself is not enough to account for radon levels, these being influenced by other factors (temperature trends, wind intensity...); a second one is that geology in this area is very complex and articulated and a local investigation is needed.

CONCLUSIONS

The used methodology permits to trace maps of radon concentration normalized to ground floor, that is a more sensible indicator (not being dependent on distance from soil but on geology only), or to
local housing stock, more representative of dwellings condition.

Actually about 45% of the scheduled project has been completed and the results give an indicative preliminary information of areas with elevated radon levels of Veneto.

Correlation with geology exists but, to explain actual data investigation, it has to be deepened.

Techniques of infilling and smoothing will be applied in order to cover the scheduled rectangles actually not inhabited and to smooth over distortion due to not statistical sampling; purely geometrical algorithms (Wrixon et al., 1988) and more sophisticated ones (Prince et al., 1996) are to be tested.

The completion of the project is expected for the end of 1999.

ACKNOWLEDGEMENTS
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REFERENCES
Table 1: Current state of survey (beginning of 1999)

<table>
<thead>
<tr>
<th>Grid rectangle</th>
<th>Dwellings</th>
<th>Fraction of dwellings in investigated area (x1000)</th>
<th>Fraction of Veneto dwellings (x10000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled</td>
<td>289</td>
<td>1445</td>
<td>9.3</td>
</tr>
<tr>
<td>Monitored</td>
<td>120(^{(a)})</td>
<td>650(^{(b)})</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(a) at least two dwellings included
(b) for 120 dwellings the annual value is a projection of the six months measure (see section 2.3.1)

Table 2: Indoor radon concentration relative to floor of monitored room: absolute value and normalized to ground floor value are reported

<table>
<thead>
<tr>
<th>Detection floor</th>
<th>Ground</th>
<th>First/Ground</th>
<th>(&gt;First)/Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon level [Bq/m(^3)]</td>
<td>63.3±3.3</td>
<td>51.5±1.9</td>
<td>40.2±2.0</td>
</tr>
<tr>
<td>Ground floor normalized value</td>
<td>1</td>
<td>0.813±0.012</td>
<td>0.635±0.0015</td>
</tr>
</tbody>
</table>
Figure 1: Current state of the survey
Figure 2: Regional housing stock according to Italian Census (1981)
Figure 3: Percentage of dwellings with radon levels exceeding 600 Bq/m$^3$ (data normalized to regional housing stock)