

# Remarks on the Variability of Radon Indoor Concentrations in Italy

Romolo Remetti

*Department of Basic and Applied Sciences, Engineering "Sapienza" University, Rome, Italy*

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**Abstract:** From a geological point of view the Italian territory, compared with other European nations, is characterized by complex situations due to past and current tectonic activities related to seismicity, to the presence of an intense volcanism, especially in western and southern sides of Italy, and to the presence of thermal springs. As a direct consequence, radon concentration, notwithstanding a mean value of  $77 \text{ Bq/m}^3$  for all the national territory, exhibits a significant standard deviation; for instance, in some towns situated in north of Rome radon concentrations in dwellings may reach values up to  $400\text{-}500 \text{ Bq/m}^3$ . This study presents the results of a series of measurements, carried out by means of a Genitron AlphaGuard, in different areas of Italy. In some cases, also the historical past of Italy may play a certain role on radon concentrations; for instance, measurements carried out in dwellings situated over a Roman catacomb of two thousand years ago have shown anomalous results.

**Key words:** Radon, indoor concentration, geological variability.

## 1. Introduction

Radon, in particular the radionuclide  $^{222}\text{Rn}$  that belongs to the  $^{238}\text{U}$  decay chain, represents the most important contribution for the effective dose received by population from the Natural Background of ionizing radiation. It contributes for  $1.26 \text{ mSv}$  to the mean value of  $2.48 \text{ mSv/year}$  (world mean value) [1]. By the International Agency for Research on Cancer (IARC), radon and its decay products are classified as carcinogenic to humans (Group 1) [2]. Radon and its decay products are ubiquitous in soil, water and air. Inside buildings the primary source is the ground under the structure. As a direct consequence, the geographical variability of indoor radon concentrations is associated strictly to the geological nature of the ground. In particular, radon transport to the surface, which is described by emanation, diffusion, advection and adsorption models, depends on different physical, geological and ambient

parameters, such as the geology of the area, geochemical composition of the soil, its porosity and permeability, grain size, soil humidity, temperature and atmospheric pressure [3].

From a geological point of view, Italian territory, compared with other European nations, is characterized by complex situations due to past and current tectonic activities related to seismicity, to the presence of an intense volcanism, especially in western and southern sides of Italy, and to the presence of thermal springs [4]. As a direct consequence, radon concentration, notwithstanding a mean value of  $77 \text{ Bq/m}^3$  for all the national territory, exhibits a significant standard deviation [5]; for instance, in some towns situated in north of Rome, radon concentrations in dwellings may reach values up to  $400\text{-}500 \text{ Bq/m}^3$  [6, 7]. It is worth to note that according to ICRP Publication 103 [8], also a mean value of  $77 \text{ Bq/m}^3$  in dwellings may be considered as "high".

As a direct consequence, the need for remedial actions operated on buildings with the aim to reduce indoor radon concentrations is becoming pressing. But

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**Corresponding author:** Romolo Remetti, professor, research fields: radioprotection, nuclear wastes, nuclear measurements. E-mail: romolo.remetti@uniroma1.it.

standardization of remedial actions in Italy may be a very difficult task, due to extremely different typologies of situations which may be encountered.

This work presents experimental results obtained in different parts of Italy; measurements were carried out in semi-continuous mode, i.e., by recording radon concentration every ten minutes. Such a procedure made possible to record the concentration variation along the same day, thus allow to set correlations with ambient parameters such as pressure, temperature and relative humidity.

## 2. Measurement Technique

Measurements have been carried out by means of a Genitron Alphaguard PQ2000 (Fig. 1). This instrument makes use of an ionization chamber joined to an alpha spectrometer and a to a DSP (Digital Signal Processing) unit for the recognition of the pulse shape due to radon (essentially  $^{222}\text{Rn}$ ). The presence of the alpha spectrometer and of the DSP analyzer, together with the protection from magnetic fields, vibrations and humidity, diminishes interferences and assures a large range of measurement, from  $2 \text{ Bq/m}^3$  to  $2 \text{ MBq/m}^3$ , with a sensitivity of  $4.5 \text{ cpm}/100 \text{ Bq/m}^3$ . Further, utilization of alpha spectroscopy and DSP analyzer eliminates interference from X and gamma radiations, tritium and  $^{133}\text{Xe}$ . Alphaguard is also capable to measure ambient parameters such as air pressure (850-1,100 mbar, resolution 0.1 mbar), relative humidity (0%-100% RH, resolution 1% RH) and temperature (from -20 to 65 °C, resolution 0.1 °C). Results are recorded every 10 minutes and the instrument is capable to work battery operated continuously up to 10 days. Collected data, which are associated to the absolute time of measurement, are stored in the instrument memory and can be uploaded on PC by means of a RS232 interface. It is important to highlight that the capability to record climatic parameters allows multiparameter analysis of the correlations with radon concentration [9].



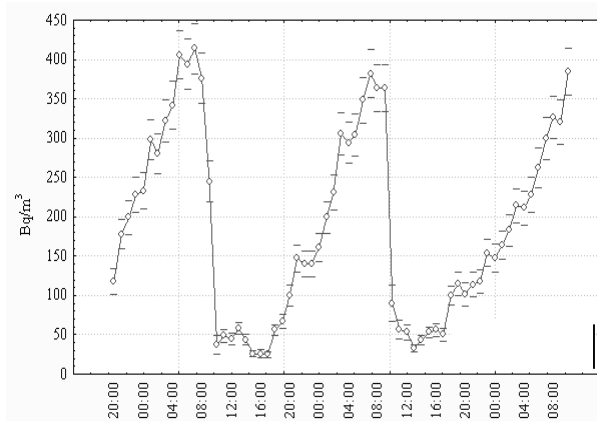
Fig. 1 Alphaguard PQ2000.

## 3. Experimental Results

The experimental measurements have been carried out in the area of the Department of Basic and Applied Sciences for Engineering of “Sapienza” University, in Rome, and in other two areas which exemplify the great variety of situations that may be encountered in Italy. They were the towns of Tivoli, an ancient (about 1215 B.C) small town near Rome, and Matera, in south of Italy. In Matera measurements were carried out inside one of the *Sassi*, the characteristic dwellings dug into the rock, originated from a prehistoric (troglodyte) settlement, that are suspected to be some of the first human settlements in Italy [10].

### 3.1 Sample n.1 Tivoli

The first measurements have been performed in the area of Tivoli, in the Prenestini Hills, a mountain range is characterized by a significant thickness of volcanic sediments, such as *tufo* and *pozzolana*. Measurements have been carried out inside a flat, utilized as private habitation, with *tufo* walls, at the first floor of a structure built on rocky soil of the type *tufo lionato*, a kind of soil created by different debris of volcanic origin. Fig. 2 represents the results of three days of continuous measurements, with data collected every ten minutes. Data have been collected during the usual utilization of the flat. Fig. 2 is evident the characteristic profile of radon concentration in absence of any artificial ventilation system: it grows quickly during the night but in the morning it falls down abruptly in coincidence of the aperture of doors and windows.



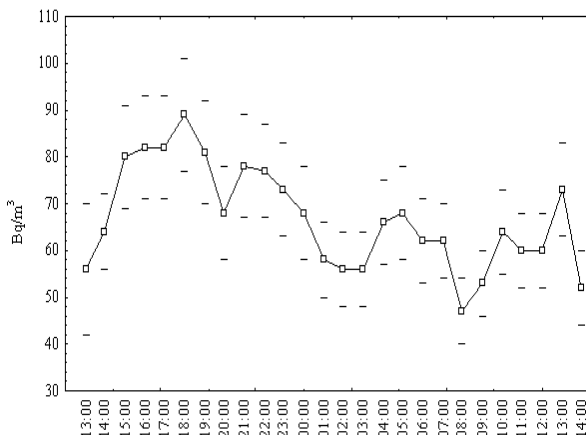
**Fig. 2 Radon concentration variation. Sample n.1** 25 Bq/m<sup>3</sup> (min), 414 Bq/m<sup>3</sup> (max), 188 Bq/m<sup>3</sup> (mean). Temperature 17.9 °C (mean), air pressure 978 mbar (mean), relative humidity 51% (mean).

### 3.2 Sample n.2 Matera

Measurements have been performed inside a house dug into the rock, one of the famous *Sassi*. Data have been collected for 24 h (one record every 10 min); during the measurement the house remained closed, without natural ventilation. Results are showed in Fig. 3. The low concentration values are due to the nature of the soil, essentially calcarenite, carbonate lithofacies of shallow marine environments.

### 3.3 Sample n.3 Rome

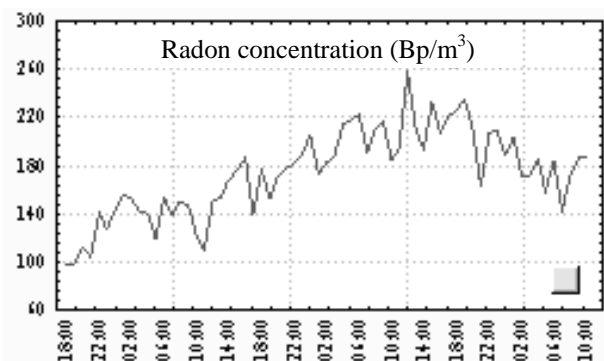
Measurements have been carried out in the area of



**Fig. 3 Radon concentration variation. Sample n.2** 47 Bq/m<sup>3</sup> (min), 89 Bq/m<sup>3</sup> (max), 66 Bq/m<sup>3</sup> (mean). Temperature 17.7 °C (mean), air pressure 980.8 mbar (mean), relative humidity 75.8% (mean).

the Department of Basic and Applied Sciences for Engineering of “Sapienza”, the first University of Rome. The department is composed by different buildings with the same construction typology; in particular, they are characterized by *tuffo* walls and are built on rocky soil of *tuffo lionato* originated by a pyro-clastic flow and characterized by deep fissures. Fig. 4 shows the variation of radon concentration obtained for a room classified as “Laboratory of Nuclear Measurements Unit 1”. Figs. 5-7 report the variation of atmospheric pressure, relative humidity and ambient temperature. Measurements have been performed during a week-end, with doors and windows closed, and, as a consequence, the growth of radon is enough regular. It may be noted only a discontinuity between the abscissas 10:00-14:00 due to the entrance of a guardian inside the laboratory: it caused a diminution of the radon concentration, due to the opening of the door, a peak of temperature and of relative humidity. Radon concentration is not negligible; this may be due to the fact that the laboratory is partly below ground level, and as a consequence a certain fraction of radon derives not only from the subsoil but also from the terrain leaning against the walls.

The land surface is covered with asphalt, and it acts as a seal, concentrating gas flow under the building, further, the shallow foundation is realized in *tuffo*, and the floor lays on a crawl space which is not ventilated. All these conditions raise convective flux from bottom



**Fig. 4 Radon concentration variation inside the Laboratory of Nuclear Measurements Unit 1.** 100 Bq/m<sup>3</sup> (min), 260 Bq/m<sup>3</sup> (max), 162 Bq/m<sup>3</sup> (mean).

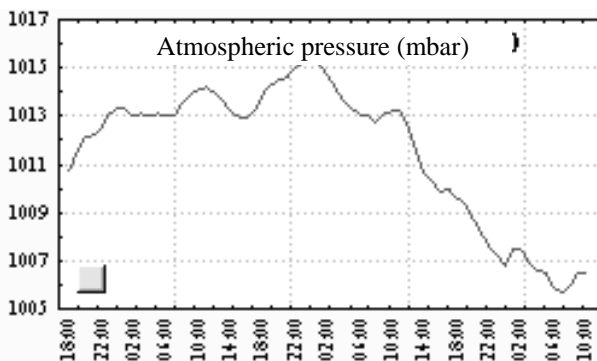


Fig. 5 Atmospheric pressure variation inside the Laboratory of Nuclear Measurements Unit 1.

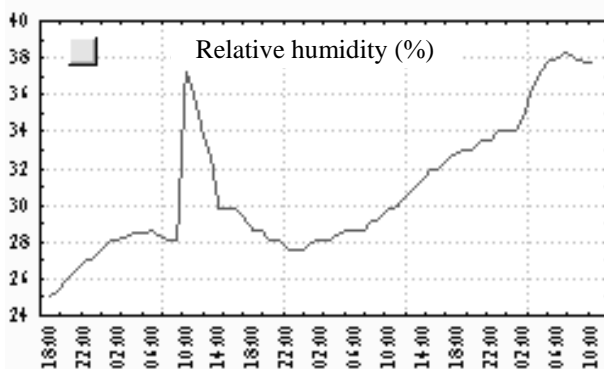


Fig. 6 Relative humidity variation inside the Laboratory of Nuclear Measurements Unit 1.

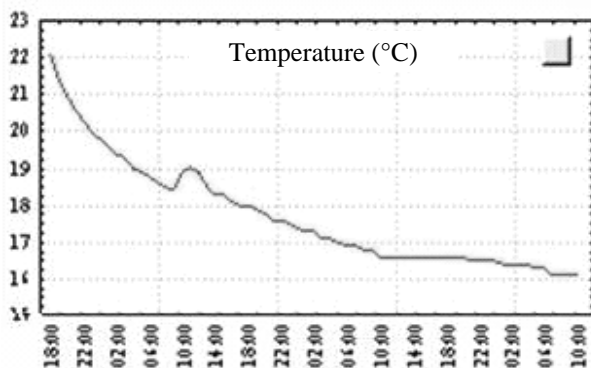


Fig. 7 Temperature variation inside the Laboratory of Nuclear Measurements Unit 1.

to top due to a positive pressure gradient between the soil in the internals of the building.

The same measurements have been repeated for another room classified as “Laboratory of Nuclear Measurements-Unit 2”, that is endowed with a mechanical ventilation system. Measurements with the ventilation system turned off gave results similar to the preceding ones (Fig. 8), while with the

ventilation system turned on the concentration reduced drastically; as Fig. 9 shows the maximum value of radon concentration is about  $80 \text{ Bq/m}^3$  with a mean value of about  $15 \text{ Bq/m}^3$ . The same measurements have been repeated for all the rooms of the department, giving a mean value of  $215 \text{ Bq/m}^3$  with a standard deviation of  $18 \text{ Bq/m}^3$ , and always producing the expected trends, for instance the reduction of the radon concentration for top floors. But analyzing two rooms of the Mathematics section of the Department, identified as B15 and B16, a quite different situations was outlined, characterized by very high radon concentrations, of the order of more than  $1,000 \text{ Bq/m}^3$ . Obviously measurements were repeated together with a check of the instrument calibration but results didn't change; Fig. 10 reports the results of a measurement carried out in room B15 for an entire week.

The rooms are situated at the low ground and the construction typology is the same of all the other buildings of the department; also the age of construction is the same. A survey action intended to discover eventual “orphan source” was carried out but it was unsuccessful.

Only by chance, studying ancient archeological reports, the Author was able to formulate a possible explanation. The entire area of the department, is erected on a Roman catacomb, called *Catacomba di S. Ippolito* (St. Ippolitus Catacomb), built about in 200 A.D. The catacomb is characterized by five levels of galleries of different depths; sometimes the galleries were obtained by the broadening of abandoned water conducts. The catacomb is in bad state of conservation, and during the WWII suffered the consequence of a bombardment [11]. As a direct outcome it doesn't belong to the current tourist circuits and information on it are scarce. Thanks to the Vatican Institute of Christian Archeology (Christian catacombs are competence of the Holy See and not of the Italian Government) the Author was able to recover a map. The overlay of the map of the subsoil with the actual map highlights a singular coincidence.

Fig. 11 shows that one of the main galleries of the catacomb is situated under the rooms 15 and 16 of the

mathematical section of the department (Building B in Fig. 11). In such a situation it is possible to suppose

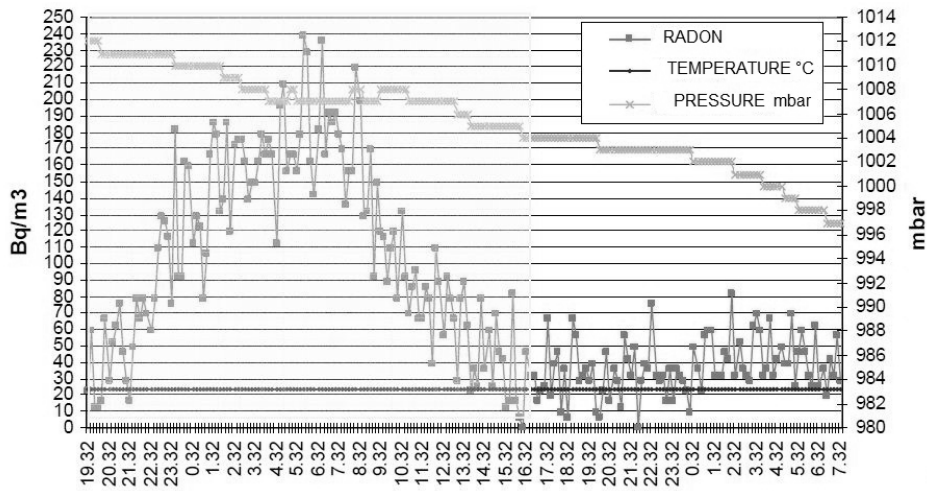


Fig. 8 Radon concentration variation. Lab. of Nuclear Measurements, Unit 2 ventilation system off.

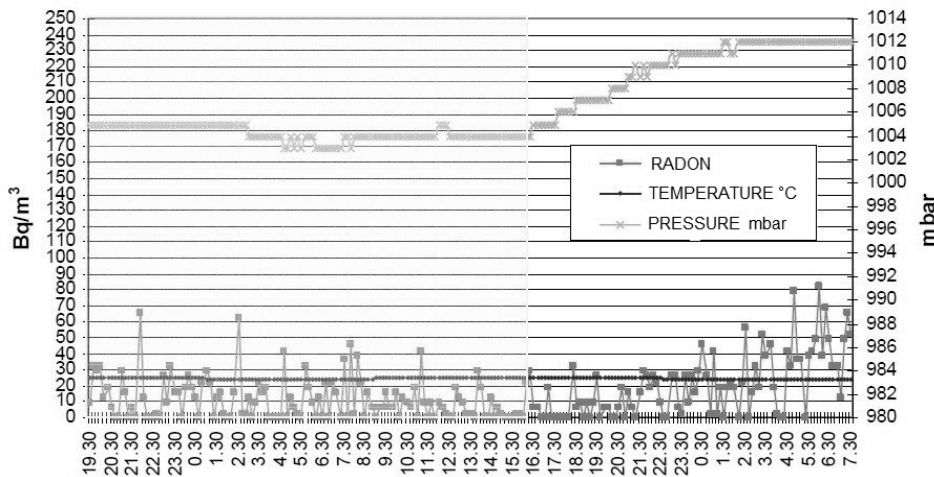


Fig. 9 Radon concentration variation. Lab. of Nuclear Measurements, Unit 2 ventilation system on.

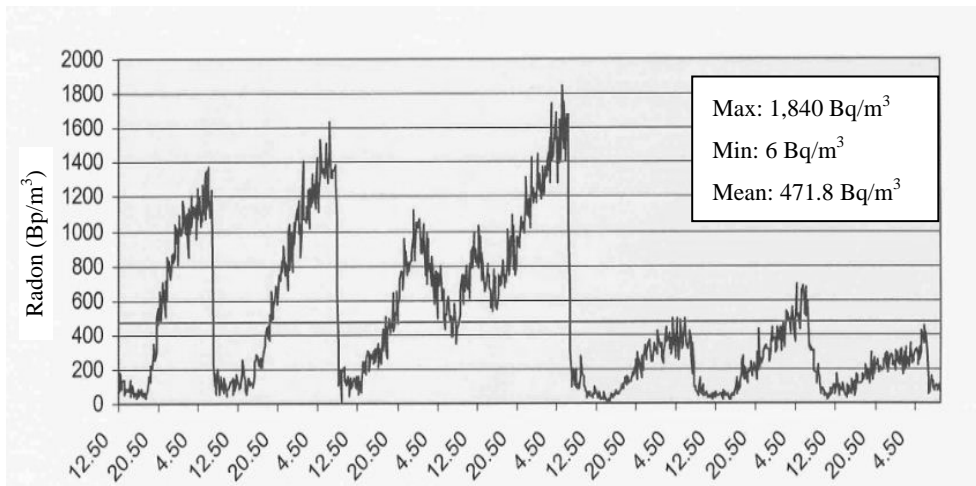
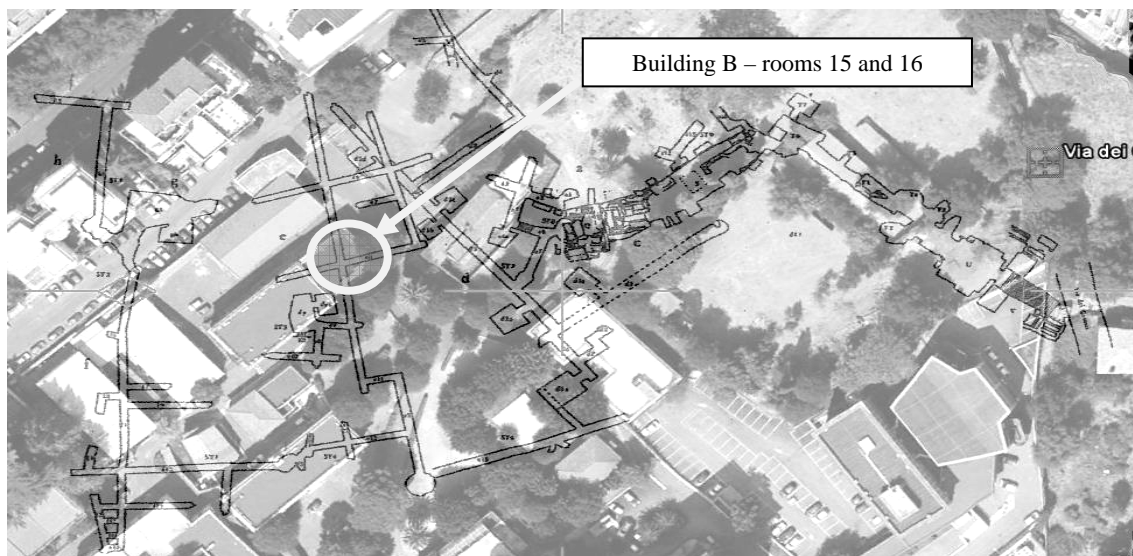


Fig. 10 Radon concentration variation vs. time for room 15 of building B seven days measurement.



**Fig. 11** The area of the Department of Basic and Applied Sciences for Engineering of “Sapienza” University (from Google Earth) overlapped with the map of St. Ippolito Catacomb (from Vatican Institute of Christian Archeology).

possible influences between subsoil air flows and radon concentrations on the surface.

#### 4. Conclusions

As regards daily variations, experimental results highlight the fundamental role of ventilation, both natural and forced, in the reduction of radon concentration of dwellings. The concentration depends strongly on the condition of use of a generic room, and usually the natural air flow caused by the aperture of the door and of a window is enough to reduce radon concentration to acceptable values. It was recognized also the negative effect of asphalt all around a construction: it acts as a seal and forces the gas to flow within.

As regards the particular Italian situation, apart from its geological complexity, also history is a parameter that must be considered when dealing with radon concentration inside dwellings. Practically in every Italian city or small town it is sufficient to dig few meters of soil to meet a historical ruin that, as in the case of catacombs, may influence the movement of underground air flows.

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