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# Correlation of the activity concentration of gas radon in environments located on ground floor and underground level

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**Summary.** — In Italy, workers' exposure to radon gas is regulated by the Legislative Decree n. 241/00 and concerns only underground workplaces such as caves, tunnels, catacombs and mines, establishing 500 $Bq/m^3$ as the limit value of activity concentration of radon. The Directive Euratom 59/2013 has introduced 300 $Bq/m^3$ as a reference level and the indication to carry out measurements in all public buildings located at the basement and ground level. The transposition by the member states scheduled for February 2018 has not yet taken place so in anticipation of the imminent transposition of the Directive by Italy, the goal of this preliminary work is to demonstrate the importance of monitoring the ground floor environments since they could have significant radon concentrations, though it is not subject to a legislative requirement. Usually the measures have a duration of 12 months, but for this preliminary approach, electrets detectors were used, in SLT configuration (Short chamber and Long Term electrets), for 30 days, in workplaces located on the ground floor and in the basement. Results show high values that can cause workers to exceed the radon maximum dose levels.

## 1. – Introduction

The radon gas is produced from the decay series of $^{238}U$ or other elements like thorium or actinium and, for this reason, its distribution is very variable in the Earth's crust. So $^{222}Rn$ and its progenies are thus ubiquitous and represent the major natural exposure source to ionizing radiation for humans [1]. When the gas accumulates in confined spaces, it could become a risk for human health.

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The International Agency for Research on Cancer (IARC) [2] has classified radon gas as a category-1 agent and defined it as a human carcinogen since 1988; on the other hand, EPA 2003 has reported that radon is the second risk factor for lung cancer after smoking [3]. In particular, lung cancer risk depends on the effective alpha dose received by lung tissues from inhalation of radon and its decay products [4]. Even if the onset of lung cancer by radon gas is a stochastic event and not related to the dose-effect relationship, the International Commission on Radiological Protection (ICRP) [5] has established an action level between 400 and 600 $\mathrm{Bq/m^3}$. In Italy, the Legislative Decree n. 241/00 that requires that the employers limit the exposure of workers through the control and the limitation of the radon levels in all underground workplaces and imposing the action level for the workplace to 500 $\mathrm{Bq/m^3}$ [6]. On December 5, 2013, the EURATOM Council issued the Directive 2013/59 laying down basic safety standards for the protection against dangers arising from exposure to ionizing radiation, and repealing Directives 90/641/Euratom, 89/618/Euratom, 97/43/Euratom, 89/618/Euratom and 2003/122/Euratom over. In particular, in the article *Radon in the workplace*, it is established that radon measurements will have to be performed in the workplace located on the ground floor and in the basement and the national reference in air of the average annual activity concentration in the workplace should not exceed 300 $\mathrm{Bq/m^3}$ [7]. The novelty, apart from lowering the action limit, is the addition of the ground floor as a place to be measured. Italy should have implemented this directive on 6 February 2018 on the basis of the 2014 European Delegation Law: to date this has not yet occurred.

Some measurements have already been taken in workplaces of the Campania region (Italy) other than those indicated by the legislation in force [8-10] and results showed high values and hot spots. For this reason, it seemed necessary to carry out targeted investigations also in workplaces located both in the ground floor and in the basement to study the possible relationship between the two different environments.

## 2. – Materials and methods

Measurements were performed using the E-Perm system. It is a passive method for calculating activity concentration of radon indoor, based on the measurement of the variation of the potential induced on an electret by the collection of ions produced by the radiation inside a chamber of known volume [11,12]. The system consists of a chamber and an electret. The chambers used are of type S (for short measurements) and of type L (for long measurements). Both E-Perm chambers have an air inlet equipped with a millipore filter, which allows the radon diffusion but not the diffusion of its decaying daughters.

The electret is an electrically charged Teflon disc; two types of electrets are commercially available: the short-term electrets (ST) that have high sensitivity, and the long-term (LT) electrets, with lower sensitivity. Furthermore, each electret is identified by a barcode. The initial surface potential of the electret is about 750 volts, while the minimum use voltage is around 200 volts.

Generally, the exposure times, depending on the configuration, are

- SST configuration 3–7 days;
- SLT configuration 30–90 days;
- LST configuration 15–30 days;
- LLT configuration 6–12 months.

TABLE I. – *Values of constants A, B, C based on the E-Perm's configuration.*

| Configuration | Constant $A$ | Constant $B$ | Constant $C$ |
|---|---|---|---|
| SST | 1.6978 | 0.0005742 | 0.35 |
| SLT | 0.1400 | 0.0000525 | 0.35 |
| LST | 0.2613 | 0.0001386 | 0.59 |
| LLT | 0.02383 | 0.004293 | 0.59 |

To obtain the radon activity concentration starting from the voltage difference of the electret and from the exposure time it is necessary to carry out the two following calculations.

The calibration factor ($CF$), fixed a chamber-electret configuration, is defined as the voltage variation of the electret for the exposure to a radon activity concentration of $1\,\mathrm{Bq/m^3}$ for one day. The CF is in linear relation with the voltage drop of the electret in the range 750–150 V, and it is calculated as

$$CF\left[\frac{\mathrm{Volts}\cdot\mathrm{m}^3}{\mathrm{Bq}\cdot\mathrm{days}}\right]=\frac{A+B\cdot\frac{\mathrm{I}+F}{2}}{37}, \tag{1}$$

where the term $(1+F)/2$ represents the mean voltage value ($MVV$), $A$ and $B$ are calculation constants for a given camera-electret configuration and $I$ and $F$ are the initial and final voltage values of the electret. 1/37 is the factor that allows expressing the concentration directly in $\mathrm{Bq/m^3}$.

The values of the constants $A$ and $B$ are reported in Table I.

The radon activity concentration ($RnC$) is then calculated using $CF$:

$$RnC[\mathrm{Bq/m^3}]=\left(\frac{I-F}{CF\cdot D}-BG\right), \tag{2}$$

where $BG = C * R\_y$ and $I$ and $F$ are the initial and final voltages of the electret, $D$ is the exposure period in days, $CF$ is the calibration factor, $BG$ is the equivalent radon concentration due to the environmental gamma background, $R_y$ is the background expressed in nGy/h, $C$ is the calculation constant for a given configuration.

The reading of the initial and final voltage of the electrets, whose difference is necessary for the calculation of the concentration of radon gas activity, is carried out manually by means of an electret voltage reader [13].

For this preliminary study, seven commercial activities were selected. They are located in the historic center of Naples, and have some common characteristics:

– year of construction between the end of the 1800s and the beginning of the 1900s;

– Neapolitan tuff as construction material;

– presence of underground rooms and rooms in the ground floor.

TABLE II. – *Spreadsheet and acquisition of electret reading.*

| Code | Position | Initial voltage (V) | Final voltage (V) | Gamma background (nGy/h) | Exposure detector (days) | Radon concentration (Bq/m$^3$) | Uncertainty 1 sigma (Bq/m$^3$) |
|---|---|---|---|---|---|---|---|
| SJW083 | Loc 1_floor 0 | 748 | 666 | 100 | 30 | **266** | **17** |
| SJW117 | Loc 1_floor -1 | 734 | 599 | 100 | 30 | **484** | **28** |
| SJW187 | Loc 2_floor 0 | 610 | 357 | 100 | 30 | **959** | **51** |
| SJW273 | Loc 2_floor -1 | 616 | 365 | 100 | 30 | **948** | **51** |
| SJW199 | Loc 3_floor 0 | 727 | 581 | 100 | 30 | **531** | **30** |
| SJW267 | Loc 3_floor -1 | 728 | 474 | 100 | 30 | **990** | **53** |
| SJW548 | Loc 4_floor 0 | 748 | 499 | 100 | 30 | **922** | **49** |
| SJW098 | Loc 4_floor -1 | 750 | 509 | 100 | 30 | **889** | **48** |
| SJW138 | Loc 5_floor 0 | 761 | 597 | 100 | 30 | **598** | **33** |
| SJW135 | Loc 5_floor -1 | 732 | 584 | 100 | 30 | **538** | **30** |
| SJW242 | Loc 6_floor 0 | 761 | 709 | 100 | 30 | **171** | **13** |
| SJW132 | Loc 6_floor -1 | 731 | 455 | 100 | 30 | **1234** | **65** |
| SJW346 | Loc 7_floor 0 | 607 | 504 | 100 | 30 | **431** | **25** |
| SJF364 | Loc 7_floor -1 | 508 | 233 | 100 | 30 | **1356** | **71** |

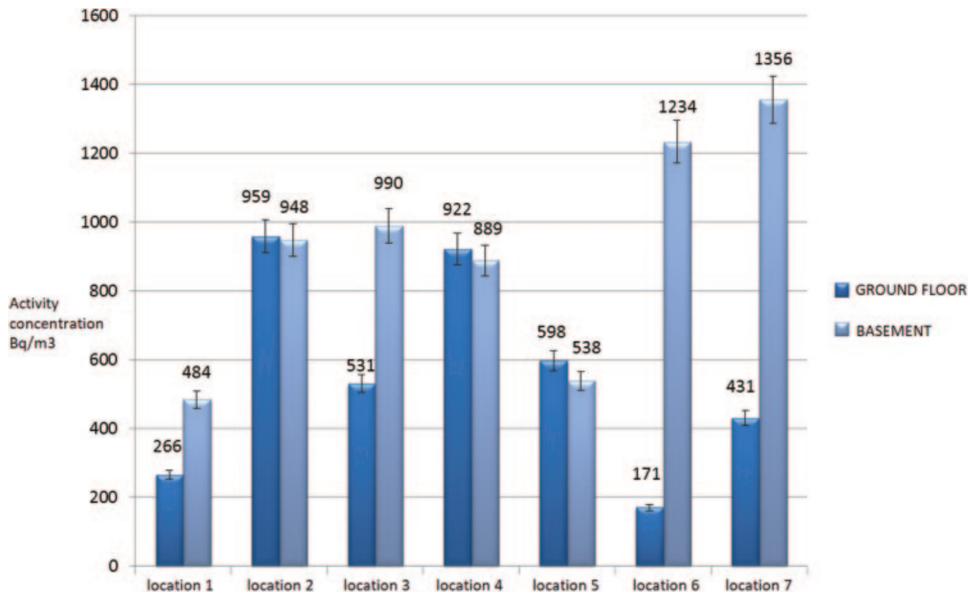


Fig. 1. – Distribution of radon activity concentrations both on ground floor and in the underground.

## 3. – Results and discussion

Being preliminary and investigative measurements, electrets in SLT configuration were used for a period of 30 days reporting the results shown in table II. Usually annual measurements are performed, as the radon gas is subject to seasonal variations (spring-summer and autumn-winter) and environmental variations, therefore, the annual duration is representative of every type of environmental variations.

Each detector has been installed, according to the main guidelines, far from heat sources and drafts [14].

The results are shown in fig. 1.

From the results obtained, it is clear that radon gas concentration in the basement is higher than on the ground floor (from 484 to 1356 $\mathrm{Bq/m^3}$). The values depend on different ventilation systems in the places examined. In the locations 6 and 7, the rooms in the basement remained closed to the public for several months.

Also the ground floors presented quite high radon concentrations with the exception of the locations 1 and 6 characterized by a more frequent air exchange system.

If the values obtained are compared to the limit values indicated in the Legislative Decree 241/00 in force (500 $\mathrm{Bq/m^3}$) and in the new Euratom Directive 59/2013 (300 $\mathrm{Bq/m^3}$), it is clear that all the chosen locations exceed the limits. Only the ground floors of locations 1 and 6, with an active air extraction system, have a radon gas concentration under the limit of both Legislative Decrees.

## 4. – Conclusions

In conclusion, it is very important to monitor the concentration of the radon gas activity in underground working environments to fulfill legislative obligations (D.Lgs 241/00). In particular, this study has revealed the need of investigating and studying the situation of places open to the public and located on ground floor, in view of the imminent transposition of the Euratom Directive 59/2013. In fact, high values that can result in exceeding the radon maximum dose levels foreseen for workers, have been measured.

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