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Indoor radon measurements and annual effective dose estimation in different university workplaces in Urbino (Central Italy)

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ABSTRACT

Background and aim. Radiation is a natural part of the environment, and radon gas is a critical source of exposure due to its abundance and mobility. Indeed, radon can reach and accumulate in confined living and working places. Inhalation of radon and its decay progenies is a significant risk factor for human health. This investigation aims to measure the annual average of radon concentration in in different workplaces of Urbino University.

Methods. The study was carried out for two consecutive semesters in 48 workplaces using CR-39-type detectors.

Results. The data revealed a mean value of radon concentration of 113.10 Bq/m3, higher than the national average value of 70 Bq/m3 but below the 300 Bq/m3 threshold indicated by Directive 96/29 EURATOM 2013. In the locals with higher radon levels (>300 Bq/m3), the effective dose estimation showed values below the limit of 6 mSv (from 3.27 to 5.12 mSv), except for one workplace identified as a technical room (no frequented by personnel).

Discussion. Overall, in this investigation, 85.4% of the examined premises were below the reference level for indoor radon concentration (300 Bq/m3), while14.6% showed radon concentration higher than 300 Bq/m3 but in areas little or no frequented by staff at all, such as technical rooms (21.4%) and archives (20%), or libraries (37.5%) respectively.

Conclusions. Our results confirm the presence of indoor radon in underground workplaces of Urbino University below the national reference level for indoor radon concentration in the air. In cases where radon values exceed this limit, the necessary interventions will be carried out, as well as new measurements to verify the effectiveness of the applied radiation protection procedures.

Introduction

The term “radon” typically refers to the combination of Radon (Rn) and its short-lived decay products (RnDP). Radon is a radioactive noble gas belonging to the 238Uranium radioactive chain, produced by the decay of 226Ra (Radium), widely distributed in soil and rocks throughout the earth’s crust, water, and in many building materials [1]. The radioactive gas, formed underground, can move freely inside buildings; in the case of locals with good ventilation, the indoor radon concentration can remain low even when radon emanation from the earth's crust is high, but in confined spaces, radon concentration can reach harmful levels for the occupants [2]. It's well-known that Rn concentration in air depends on the source's intensity and dilution factors, both influenced by weather conditions, such as humidity, atmospheric pressure, and wind conditions [3].

Indoor radon has been identified to be the second leading risk factor for lung cancer after tobacco smoking [4]. Radon is almost completely exhaled after inhalation for its long half-life (3.82 d). On the contrary, its progenies 218Po and 214Po have a shorter half-time (27 min) and, being electrically charged, can be attached to dust or smoke particles in indoor air. In the lung, during the breathing process, they reach the bronchial tissue, where they decay, emitting radioactive alpha particles that can damage the pulmonary epithelium and cause lung cancer [5]. World Health Organization [1] has established that most radon-induced lung cancers are caused by low and moderate radon concentrations rather than high radon concentrations. In 2009, the WHO report established an action level of 100 Bq/m3 for residential radon with the recommendation not to exceed 300 Bq/m3. In 2013, the European Union issued the European Directive 59/2013 [6], indicating 300 Bq/m3 as a reference level for dwellings and workplaces. This European directive was implemented in Italy in 2020 [7], confirming the 300 Bq/m3 reference level for workplaces and dwellings. In our country, according to Italian Legislation, measurements of radon concentration in underground workplaces and on the ground floor of workplaces located in identified radon-prone areas are mandatory. In this direction, surveys of occupational radon exposure have been performed on local scales in Italy [8-11] but an updated map on indoor radon levels in workplaces is not yet available [12].

This study aims to determine the indoor radon concentration in different workplaces of Urbino University (Marche, Central Italy). Specifically, the experimental design was divided into two proceeding steps: i) the elaboration of the sampling plan, including the choice of the workplaces to be monitored; ii) the exposure of CR-39 detectors for two consecutive semesters in the selected sites and related data analysis.

2. Materials and Methods

2.1. Sampling sites

The confined workplaces to be monitored were selected by the Prevention and Protection Office of Urbino University, and regardless of their intended use, underground floors, basements and ground floors were monitored. Among the structures of Urbino University, six typologies of workplaces were selected for a total of 48 different zones of each site: technical rooms (n=14), laboratories (n=11), classrooms (n=8), libraries (n=8), archives (n=5) and offices (n=2).

2.2. Monitoring, dosimeters and data analysis

Specifically, the survey was conducted in two half-year periods during 2022-2023 (the first including August 2022-February 2023, the second March 2023-September 2023) via the use of passive dosimeters of the CR-39-type detectors that respond to nuclear tracks (UNI ISO 11665-4:2021). In each monitored workplace, the dosimeters were exposed for two consecutive semesters to obtain a year of exposure. The detectors were positioned about 2 m from the floor and, when possible, approximately 20 cm from the internal wall so as not to record the contribution from the Thoron. This distance could not be respected on some premises, and as a maximal precaution, the dosimeters were positioned near the wall. To ensure accurate measurements, the detectors were not placed near ventilation systems, doors, or electrically powered appliances. In the case of premises with a surface area equal to or less than 100 m^2, multiple sampling points were identified (one every 50 m2). On the other hand, in rooms larger than 100 m^2, at least one sampling point has been provided for every 100 m^2 or fraction thereof, as per the guideline of Annex II of Legislative Decree 101/20 [7]. After each exposure period, all the dosimeters were collected and sent to Tecnorad s.r.l. (Verona, Italy) for chemical analysis following UNI ISO 11665-4. The ^{222}Radon concentration was expressed as Bq/m^3 with a 300 Bq/m^3 threshold as indicated in Council Directive 2013/59/Euratom [6].

The annual effective dose H to the workers due to the radon and its progeny was calculated as suggested by the Italian Legislation7 using the Equation:

$$H(mSv/y) = C \times T \times D$$

where C is the radon concentration (Bq/m3), T is the occupancy factor, and D (6.7 x 10-9 Sv per Bq hm-3) is the dose conversion factor assuming an average equilibrium factor between radon and its daughters of 0.4 [8,13].

3. Results and Discussion

Many reports on radon concentration in different European workplaces are available in the literature Indeed, the investigation of Clouvas and Xanthos (2012), carried out in schools and public offices as well as private enterprises in Greece, stressed that the radon concentrations varied in a building depending on the variations of the ventilation conditions and air exchange between rooms [14]. Bochicchio et al. (2014) performed a systematic survey in 334 primary schools in Southern Serbia [15], Azara and collaborators (2018) assessed radon concentration (45-140.3 Bq/m3) in schoolrooms in the Midwest of Italy [16] and Martin-Gisbert et al. (2023) examined private and public workplaces in Spain [17].

On the contrary, a few data on the radon survey in European University workplaces are available in the literature [18,19]. In this context, our investigation can help add new information on radon diffusion in the Marche Region and, more importantly, in university workplaces. For the research, 48 workplaces of Urbino University were selected, grouped into six categories (technical rooms, laboratories, classrooms, libraries, archives and offices) and monitored for the annual indoor radon concentration measurement (Table 1). The annual radon average concentration is 113.10 Bq/m3 (Table 2), higher than the national average value of 91 Bq/m3 and that of the average level of the Marche Region (40- 60 Bq/m3) for underground workplaces [20]. However, values higher than the national average of 91 Bq/m3 were evidenced only in 35.4% of the monitored workplaces and, among these, 76.5% mainly in environments little frequented (such as archives and technical rooms).

Regarding the radon survey in the Marche region, no significant measurement activities were carried out after the generic information report of the Regional Agency for Environmental Protection of the Marche (ARPAM in Italian) on the radon problem in

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2003 (updated in 2007), indicating the radon level in the range 20-40 Bq/m^3 (https://www.arpa.marche.it/radiazioni-ionizzanti/radon) [21]. In this direction, our data, even if not comparable with other relatively recent ones, results novel and in line with the indication of Council Directive 2013/59/Euratom [6]. The high annual average radon level measured in Urbino workplaces (113.10 Bq/m3) could be related to different factors, from the geomorphological characteristics of the territory, the building materials used in the selected premises to differences between day and night in long-term measurements, varied ventilation conditions (opened/closed doors), pressure and temperature conditions or the presence of minimal cracks, etc... Unfortunately, recent maps of indoor radon at a regional scale are unavailable in the literature for Marche.

As mentioned above, the radon survey was conducted in different types of workplaces. Table 2 summarizes the percentages of each type of workplace presenting an annual average of radon concentration higher than 300 Bq/m^3 as indicated by the Italian Legislation [7]. Overall, 85.4% of the examined premises were below the national reference level for indoor radon concentration in the air. Only 14.6% of the samples showed radon concentration higher than 300 Bq/m^3, in any case in areas that are little or no frequented by staff at all, such as technical rooms (21.4%), archives (20%) or libraries (37.5%) respectively. The distribution of the average radon concentrations in the different workplaces related to the floor level was presented in Figure 1, considering three subranges of radon concentration: < 240 Bq/m^3, 240 – 300 Bq/m^3 and > 300 Bq/m^3. As shown, 64.3% of underground floors, 72.2% of basements and the totality of ground floors presented radon concentrations < 240 Bq/m^3. Only 14.3% and 5.5% of underground floors and basements revealed radon concentrations between 240 and 300 Bq/m^3, respectively, while 21.4% and 22.2% of the same workplaces showed radon concentrations> 300 Bq/m^3.

The Italian Regions are responsible for mapping natural radioactivity in their respective areas, and effectively, some surveys have already been started in the past years using different protocols [16,20, 22-24]. The Italian implementation of European Council Directive 2013/59/Euratom in 2020 [6] indicates as mandatory the radon concentration measurements in underground workplaces such as caves, tunnels, cellars and mines, in spas and on the ground floor of workplaces located in identified radon prone areas. Indeed, in the recent literature, reports on Italian radon monitoring in different regions are available [9,25]. In particular, Loffredo and Quarto (2023) presented data on radon concentration in several workplaces in the Campania Region (Southern Italy), involving about 695 workplaces conducted from September 2018 to February 2022 [10]. Similarly, Lupiano and collaborators (2023) have analysed a set of 1434 average annual indoor radon measurements between 2010 and 2021 in the Calabria Region (Southern Italy), obtaining an updated specific map for a possible relationship between radon concentrations and geology [11]. In general, it can be stated that radon distribution is not uniform throughout Italy, with a high variability among regions and intra-region but a low spread among rooms belonging to the same workplace.

In the present investigation, the maximum effective dose was calculated when the radon concentration resulted between 240 to 300 Bq/m^3 or higher, hypothesizing 2000 hours spent in a year in each workplace (Table 3). As reported, the effective dose resulted below 6 mSv (from 3.27 to 5.12 mSv), except for one workplace identified as TR07 (technical room) with 6.39 mSv. It can be noted that the considered worker occupancy time was overestimated because most of the seven premises are little or no frequented by personnel (technical rooms, archives and library) and, moreover, in these locals the CR-39-type detector's distance from the wall of 20 cm of was not respected. This way, the radon concentration was certainly overestimated compared to the real concentration in the rooms, anyway indicating no risk for the occupants (ever below 6 mSv). Indeed, the Italian Legislation [7] sets the dose limit for radon exposure in workplaces equal to 6 mS/y; beyond this limit, the worker is considered professionally exposed with the consequent dose monitoring actions to be acted.

The characteristics of building materials or those of the rocks may play an essential role in the radon diffusion in these situations. Our findings agree with those of Ruano-Ravina (2023), who reported that the radon concentration increases with height [2]. Moreover, radon levels in buildings can vary according to season and housing characteristics, with higher concentrations in colder months on premises with poor ventilation and on the lower floors of houses [26,27].

In conclusion, the results of the present work confirm the presence of indoor radon in underground workplaces of Urbino University but, in most cases, at a level below the reference level of 300 Bq/m3 for indoor radon concentration in the air. In all the situations with radon values exceeding the limit, investigations are ongoing to identify the possible way by which radon is introduced, such as cracks in walls, floors, cavities, piping, cable routes for electrical systems, etc., as well as the impact of ventilation systems and air exchange rates. At the end of the investigation, the necessary interventions will be carried out, and new measurements will be performed to verify the effectiveness of the interventions and/or the need to undertake further remediation actions and radiation protection procedures.

Authors' contribution

R. Campana: Conceptualization, Writing – original draft, Data curation, Writing – review & editing. A. De Benedittis: Methodology, Formal analysis, Writing – review & editing. V. Musumeci: Review & editing. A. Gambarara: Project administration, Funding acquisition, Review & editing.

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Declaration of competing interest

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Table 1 *Type and number of the examined Urbino university workplaces according to the floor level*

Workplaces type	Basement	Underground	Ground floor
Technical rooms (n=14)	6	6	2
Laboratories (n=11)	3	2	6
Classrooms (n=8)	2	3	3
Libraries (n=8)	5	0	3
Archives (n=5)	2	3	0
Offices (n=2)	0	0	2
Total premises (n=48)	**18**	**14**	**16**

Table 2 *Annual average of radon concentration (Bq/m3) in the different types of examined Urbino university workplaces*

Workplaces type	Radon Concentration	> 300 Bq/m³ (%)
Technical rooms (n=14)	147.5	21.4
Laboratories (n=11)	34	0
Classrooms (n=8)	33.125	0
Libraries (n=8)	182.75	37.5
Archives (n=5)	244.2	20
Offices (n=2)	21	0
Total premises (n=48)	113.10	14.6

Table 3 *Annual effective dose (mSv) received by the workers in the workplaces showing annual radon average concentration from 240 to more than 300 Bq/m3, assuming an occupancy factor of 2000 h/y for a worker*

ID Workplace	Floor level	Annual radon average concentration (Bq/m³)	Annual effective dose (mSv)
TR07	basement	477	6.39
TR13	underground floor	343	4.60
TR14	underground floor	382	5.12
LR01	basement	310	4.15
LR02	basement	354	4.74
LR03	basement	304	4.07
LR04	basement	260	3.48
AR03	underground floor	315	4.22
AR04	underground floor	269	3.60
AR05	underground floor	244	3.27

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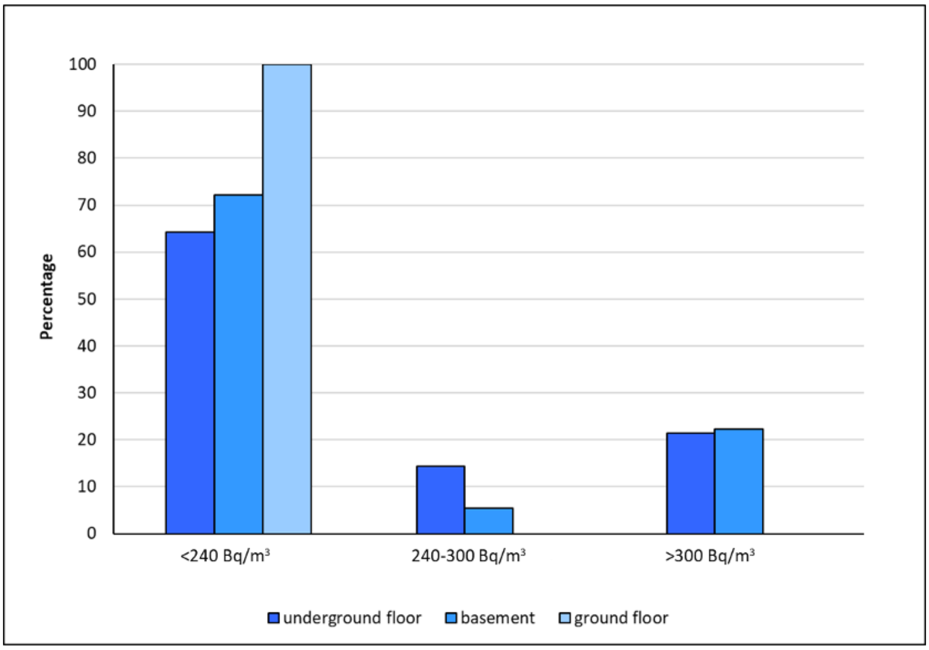
***Figure 1** Distribution of the average radon concentrations in the different examined workplaces related to the floor level (underground floor, basement, ground floor). Three subranges of average radon concentration were considered: < 240 Bq/m3, 240 – 300 Bq/m3 and > 300 Bq/m3*



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